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# ECONOMIC ASPECTS OF TRAFFIC CONGESTION
# IN THE LAKE WASHINGTON SHIP CANAL SYSTEM

by

DAVID WARREN HARNED

A thesis submitted in partial fulfillment

of the requirements for the degree of

MASTER OF SCIENCE
IN
CIVIL ENGINEERING

UNIVERSITY OF WASHINGTON

1964

Approved by ______________________________
(Chairman of Supervisory Committee)

Department ______________________________
(Departmental Faculty sponsoring candidate)

Date ______________________________

Thesis
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# PREFACE

It is the purpose of this thesis to examine both qualitatively and quantitatively various aspects of congestion in the water-borne traffic using the Lake Washington Ship Canal and the Hiram M. Chittenden Locks. The principal questions to be investigated herein are: Do congested conditions actually exist in the ship canal; what is the extent of this congestion; what is it's cost to the public; how will it affect the development of water-borne traffic patterns in the Seattle area; are measures available for the relief of this congestion; and are they economically feasible.

Pursuant to answering these questions the historical background and the sources of congestion in the Lake Washington Ship Canal will be investigated and discussed. In order to detect the influence of time upon water-borne traffic patterns, the rate of change of the pleasure boat population in Seattle and the annual fluctuation of boat arrivals at the Hiram M. Chittenden Locks will be examined and projections of these functions made for the next several years.

If congestion is discovered, possible means of alleviation will be proposed. Theory and methodology for the quantification of the effects of this congestion will be developed, necessary data will be collected and processed in such manner as is required to give a quantitative indication of the cost to the public of congestion in the ship canal due to pleasure craft traffic.

Calculations will be made of the justifiable costs of those measures proposed for the reduction of congestion and these calculations used as a basis for estimating the economic feasibility of installing the proposed improvements. Based on these data qualitative predictions of probable trends in the development of recreational water-borne traffic patterns in the Seattle area will be made and discussed.

The thesis will be concluded with a discussion of possible inaccuracy in the procedure employed and data used and the proposal of an extended methodology for a more detailed study of this problem by some interested agency.

The reader must be mindful of the fact that the imponderables of economic theory permit no precise, definitive numerical calculation of gains and losses to be made. Even the most rigorous investigation of economic questions requires numerous subjective judgements and assumptions to be made, all of which are the subject of continuing academic debate.

Any results of this investigation therefore, will partake more of the nature of an engineering estimate than of anything else. At the same time it should be remembered that those estimates are based not only upon the experience and opinions of the author but also upon those of the professional engineers who so kindly advised and guided the author throughout the time when this report was in the making. As such they are rather more than likely to be well within the limits of accuracy and credibility of more laborous although no more theoretically definable procedures.

# CHAPTER I

# THE HISTORY OF A TRAFFIC PROBLEM

## The City

If for nothing else, Seattle would be distinguished for its geometry. Situated on a narrow strip of land between Puget Sound and a great fresh water lake, all patterns of transportation have of necessity developed in conformance to this constrained configuration. Motor traffic must either run north and south, bounded by sea and lake and by lake and mountain, or else turn at right angles and seek to cross the lake on narrow ribbons of concrete stretched over pontoons. Water-borne traffic too must conform to this pattern, plying either north or south within Lake Washington or Puget Sound, or else turning to seek the sole connecting link between the two bodies of water; a search made all the more attractive by their proximity to one another. So notable is this proximity that shortly after the Civil War, the United States Navy considered locating a naval station in Lake Washington although there was no connection between it and Puget Sound in existence at that time.

## The Government Locks

At the turn of the century, Wilbur and Orville Wright were still experimenting with kites and only a few eccentrics and visionaries could conceive of a carriage being moved without the assistance of horses.

Seattle meanwhile was a rapidly expanding seaport, focus of the northwest timber industry and nourished on trade with the rich Alaska Territory and with the industrious Japanese who were busily building the fleet they would soon use to shatter the power of the Czars. With Seattle the most rapidly developing center of seaborne traffic in the United States, and in this the golden age of canal building, there is little wonder that the obvious task of connecting Lake Washington with Puget Sound should be undertaken.

In 1910 the Congress of the United States authorized the construction of a masonry locks in the narrows between Shilshole Bay and Salmon Bay, with the understanding that local governmental agencies should furnish funds for the excavation of the waterway connecting the bodies of water. Construction was begun the next year, the project being completed and opened to traffic in 1916. Lake Washington was linked with the sea. The burgeoning new waterway was opened to the timber industry and a haven created for fishermen.

In 1956 the name of the government locks was officially changed to the "Hiram M. Chittenden Locks," in honor of the man primarily responsible for their design. Figure 1 is a map of the Lake Washington Ship Canal system showing the locks, the canalized portion and intermediate waterways.

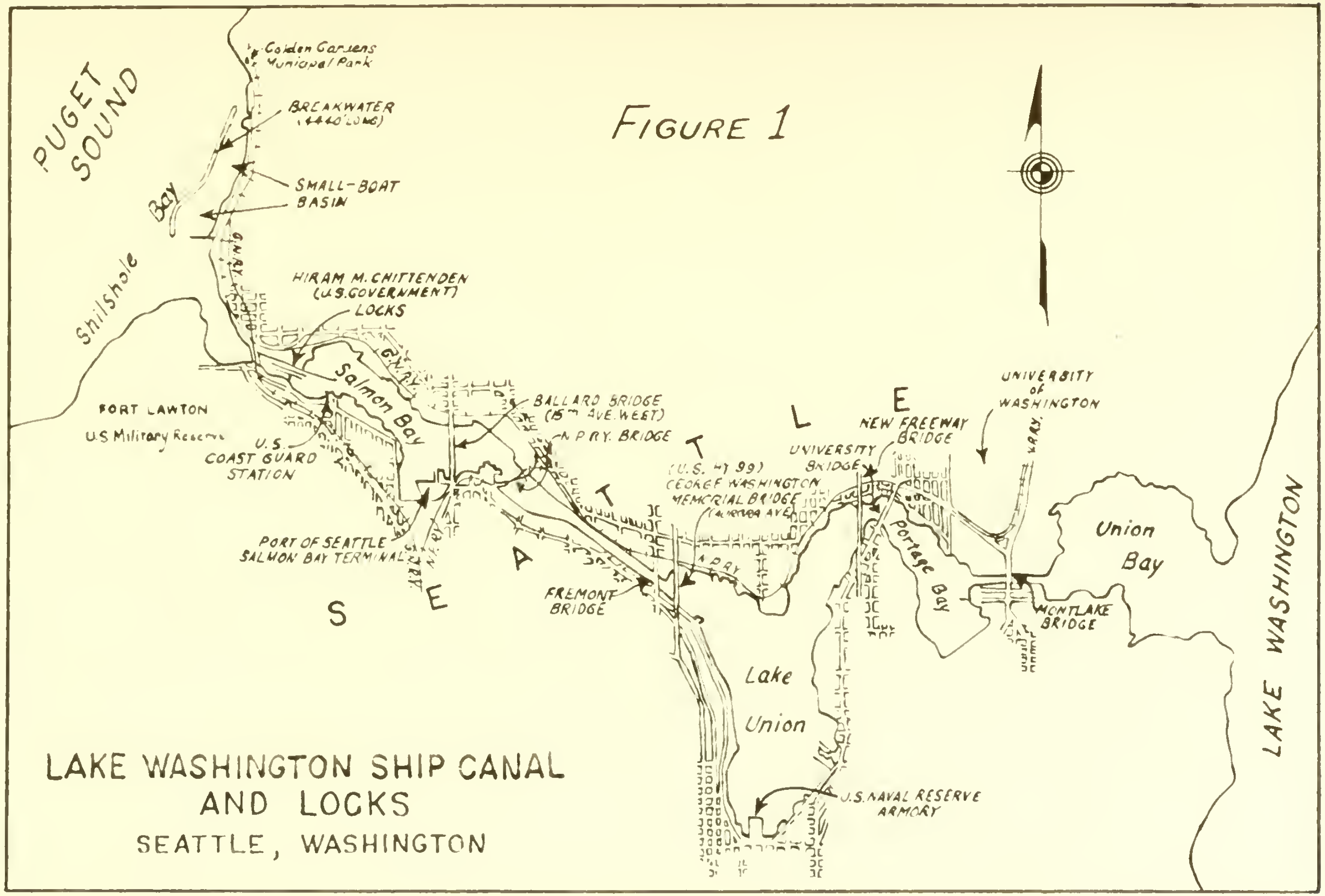


FIGURE 1

LAKE WASHINGTON SHIP CANAL
AND LOCKS
SEATTLE, WASHINGTON

## The Pleasure Boating Industry

Who in 1900 could have dreamt of the unparalleled prosperity we in the United States enjoy today? Today, with greater incomes and more leisure than ever before at their disposal, Americans in record numbers are turning to sports and diversions of all kinds, and of these yachting and pleasure boating leads the way. The 1960's have become the golden age of the boating industry. Every year has set a new record in sales of cabin cruisers, sailboats, outboard motors and outboard hulls and associated nautical equipment and goods. Yacht clubs, moorings and marinas are springing up like mushrooms. People of all income brackets are now buying boats and enjoying the thrill of sailing or motoring across open water.

Sharing equal responsibility with increased income and leisure time are technical developments within the boating industry. Some of the factors that have influenced the rapid development of the boating industry are: the proliferation of one-design sailing classes, outboard motors and hulls; the development of water-tight and warp-free marine plywood; and most of all the invention of the fiberglass hull. The availability of these virtually maintenance-free hulls has converted a considerable segment of our population from Sunday drivers to Sunday sailors.

It is estimated that more than thirty-eight and a quarter million Americans participated in recreational boating and water sports during 1963, spending two and one-half billion dollars for new and used boats, motors, accessories, safety equipment, fuel, insurance, moorage, maintenance, launching, storage, repairs and club memberships (1). The figures in Table 1 are adopted from publications of the National Association of Engine and Boat Manufacturers and the Outboard Boating Club of America (1). These data, when plotted in Figure 2, illustrate the general growth trend of recreational boating on a national scale.

For our purposes the most important portions of this curve are the projections labeled respectively "A" and "B". Projection A represents the level of growth that would have been achieved had not the business recession of 1959 and 1960 intervened. It may be seen that had growth continued at its pre-1959 rate, the national boat population would already have passed the nine million mark and could be expected to surpass eleven and one-half million by 1970. The effect of the business recession at the beginning of this decade was to reduce the total boat population by 800,000 vessels. Although the industry is obviously recovering, the 1960 peak has not yet been matched nor is the rate of expansion as great as in years prior to 1960.

Projection B consists of two dashed lines. These lines enclose an envelope containing the probable rate of increase of the boat population through 1970.

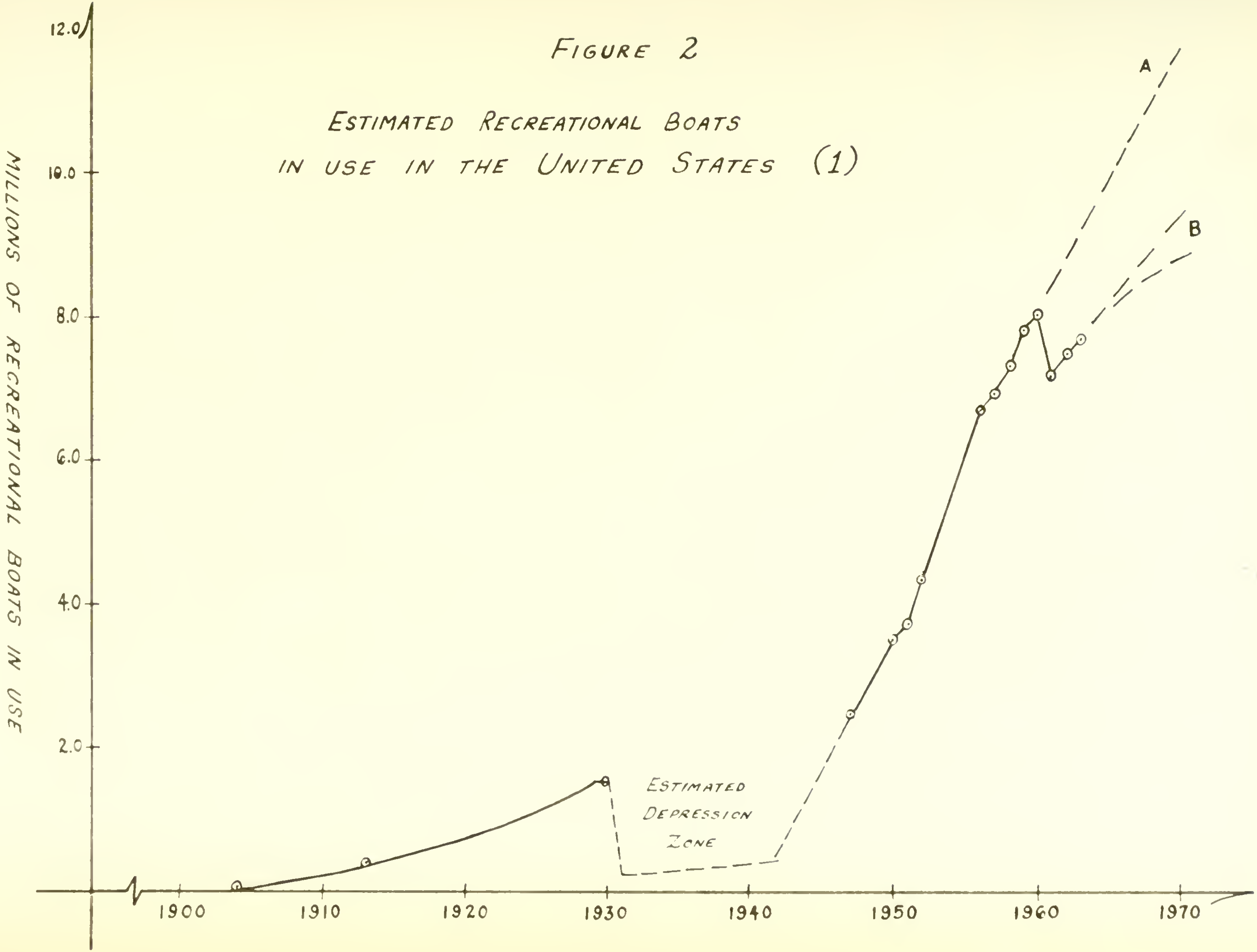
## TABLE 1

## ESTIMATED RECREATIONAL BOATS IN USE IN THE UNITED STATES

| YEAR | NUMBER |
|---|---|
| 1904 | 15000 |
| 1913 | 400000 |
| 1930 | 1500000 |
| 1947 | 2440000 |
| 1950 | 3510000 |
| 1951 | 3710000 |
| 1952 | 4333000 |
| 1956 | 6686000 |
| 1957 | 6954000 |
| 1958 | 7330000 |
| 1959 | 7800000 |
| 1960 | 8025000 |
| 1961 | 7175000 |
| 1962 | 7468000 |
| 1963 | 7678000 |

FIGURE 2

ESTIMATED RECREATIONAL BOATS IN USE IN THE UNITED STATES (1)



It may be seen that the 1960 peak will be re-achieved sometime in 1965 and that by 1970 the national boat population will have reached a level of between 8.8 and 9.4 million craft.

## Boating in Washington State

In its geographic position as a coastal state, Washington may be expected to have its share of the national boat population. Although the National Association of Engine and Boat Manufacturers and the Outboard Boating Club of America do not make estimates for individual states (1), excellent data is nevertheless available for the state of Washington. The two principal sources of such data are records of the United States Coast Guard (2,3), and the records of the Bureau of the Customs (4). These data are summarized in Table 2.

Coast Guard figures include all those motor boats in the state of Washington which are obliged to carry numbers under the Act of June 7, 1918, as amended (46 USC 288). This act requires the numbering of every undocumented vessel propelled by machinery (in whole or in part) owned in the United States and found on the navigable waters thereof, except public vessels and vessels not exceeding 16 feet in length propelled by outboard motors (3). The Washington state version of this law does not exempt motors of under 10 horsepower. The figures from the Bureau of Customs include those yachts which do not fall within the provisions of the Motorboat Act by virtue of possessing United States documents. The totals of these data are plotted in Figure 3.

## TABLE 2

## REGISTERED AND DOCUMENTED PLEASURE CRAFT IN THE STATE OF WASHINGTON

| YEAR | U.S. COAST GUARD REGISTERED MOTORBOATS (2, 3) | BUREAU OF CUSTOMS DOCUMENTED YACHTS (4) | TOTAL |
|---|---|---|---|
| 1951 | 15917 | 672* | 16589 |
| 1952 | 16731 | 660 | 17391 |
| 1953 | 17595 | 690 | 18285 |
| 1954 | 17754 | 699* | 18453 |
| 1955 | 19341 | 708 | 20049 |
| 1956 | 20876 | 713 | 21589 |
| 1957 | 22815 | 720 | 23535 |
| 1958 | 25153 | 719 | 25872 |
| 1959 | 29459 | 729 | 30188 |
| 1960 | 49757 | 805 | 50562 |
| 1961 | 61845 | 856 | 62701 |
| 1962 | 71061 | 901 | 71962 |

*Data not locally available, estimated by the author

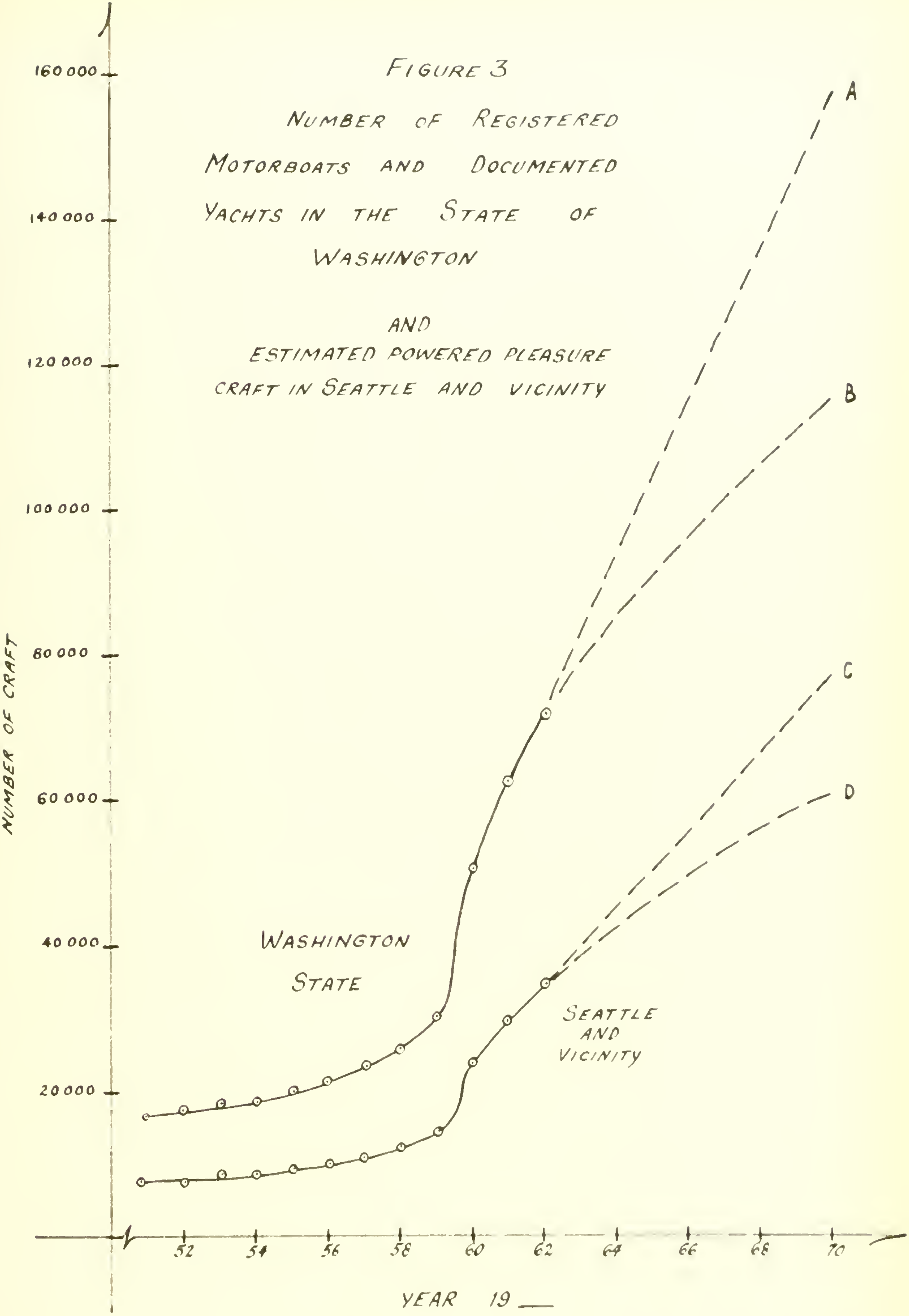


FIGURE 3

NUMBER OF REGISTERED MOTORBOATS AND DOCUMENTED YACHTS IN THE STATE OF WASHINGTON

AND

ESTIMATED POWERED PLEASURE CRAFT IN SEATTLE AND VICINITY

Note that the effects of the business recession of 1959-60 are not in evidence in this plot as they were in Figure 2. Figure 2 of course, was based upon estimated data, the implication of the difference between the two plots being that those estimates attached excessive importance to sales figures and to the general business situation of that period. In Figure 3, the rectilinear projection A and the curvilinear projection B enclose an envelope which should contain the probable growth trend of recreational boating in this state through 1970. These projections indicate that there will be between 116,000 and 156,000 registered and documented pleasure craft in Washington by 1970. Considering only the more conservative figure of these two (116,000), this would represent a growth of over 60% by 1970, only six short years away. If the arrival of vessels at the Hiram M. Chittenden Locks were to increase 60% in the next six years the results would be very nearly catastrophic. Fortunately however, as we shall see presently, boat arrivals at the locks are not increasing at nearly so rapid a rate as is the general boat population of the nation, this state, or even the city of Seattle.

## Boating in Seattle

We are interested in the past, present and future growth patterns of recreational boating in the Seattle area, since as will be demonstrated later, fluctuations in traffic through the Hiram M. Chittenden Locks are principally dependent upon pleasure craft rather than upon commercial traffic.

The establishment and forecasting of these trends is however, not so quickly or easily done for Seattle as it was for the entire nation or for the state of Washington.

Attention has already been drawn to Seattle's singular geometry. The Seattle metropolitan area in our time includes within its boundaries very nearly the entirety of Lake Washington. Few other urban centers possess the wealth of shoreline and water surface that are available in Seattle. As a result, Seattle has an extraordinary concentration of pleasure craft in proportion to its population. For instance, in 1950 it was discovered that the number of pleasure craft in Seattle in proportion to its population was more than six times the national average surpassed in this respect only by Juneau, Alaska and Ogdensburg, New York (5). These figures however, were based on a registration law that was not Coast Guard approved and which tended to require registration of a greater proportion of the total number of recreational craft in the state of Washington than in other states. For the same general time period Seattle was the ninth leading city in the United States in the total sales of outboard motors (1). Since this is based on total sales rather than per capita sales the suggestion still remains that Seattle possesses a considerably greater density of pleasure craft per capita than very nearly any other metropolitan area in the nation.

Data on yacht documentations is available from the Bureau of Customs broken down by cities (4); motorboat registrations by the Coast Guard however are not.

Therefore in order to estimate the number of pleasure craft in the Seattle metropolitan area, some form of correction must be applied to statewide figures of motorboat registrations. The author chose to make this correction on the basis of the population of the state of Washington as compared to that of Seattle and its environs. Table 3 shows the data and calculations involved.

Data published in the Statistical Abstract of the United States (6), on the population of the state of Washington and that of Seattle and vicinity for the years 1950 and 1960 were used to obtain the relative ratio between city and state in these two years. A straight-line interpolation and extrapolation was made of this ratio between the two census years. The calculated ratios for each year were then multiplied by the number of registered motorboats in the state that year to obtain the estimated number of motorboats over 10 HP in Seattle and vicinity.

Since these figures do not include powered craft under 10 HP, a correction factor of 1.2 was used to estimate the total number of powered craft in Seattle and vicinity excluding documented yachts. This correction factor of 1.2 was developed on the basis of sales figures for outboard motors under 10 HP (1), and from subjective estimates of the percentage of un-numbered motorboats passing through Hiram M. Chittenden Locks made by the author and by personnel at the locks. To the figures thus corrected were added the number of documented yachts based in Seattle, and the totals plotted in Figure 3.

# TABLE 3

## ESTIMATED POWERED PLEASURE CRAFT IN SEATTLE AND VICINITY

| YEAR | A<br>U.S. COAST GUARD REGISTERED MOTOR-BOATS (2,3) | B<br>POPULATION OF THE STATE OF WASHINGTON (6) | C<br>POPULATION OF THE SEATTLE METROPOLITAN AREA (6) | D<br>RATIO C/B BASED ON STRAIGHT LINE INTERPOLATION 1950-60 | E<br>ESTIMATED MOTORBOATS IN THE CITY OF SEATTLE OVER 10 HP EXCLUDING DOCUMENTED YACHTS AxD | F<br>ESTIMATED POWERED CRAFT IN THE CITY OF SEATTLE EXCLUDING DOCUMENTED YACHTS = 1.2xE | G<br>BUREAU OF CUSTOMS DOCUMENTED YACHTS BASED IN SEATTLE (4) | H<br>TOTAL ESTIMATED POWERED CRAFT IN SEATTLE |
|---|---|---|---|---|---|---|---|---|
| 1950 | -- | 2,379000 | 845200# | 0.355 | -- | -- | 436 | -- |
| 1951 | 15917 | -- | -- | .358 | 5698 | 6838 | 462* | 7300 |
| 1952 | 16731 | -- | -- | .362 | 5926 | 7111 | 487 | 7598 |
| 1953 | 17595 | -- | -- | .365 | 6422 | 7706 | 513 | 8219 |
| 1954 | 17754 | -- | -- | .368 | 6533 | 7840 | 522* | 8362 |
| 1955 | 19341 | -- | -- | .372 | 7195 | 8634 | 531 | 9165 |
| 1956 | 20876 | -- | -- | .375 | 7829 | 9395 | 533 | 9928 |
| 1957 | 22815 | -- | -- | .378 | 8624 | 10349 | 535 | 10884 |
| 1958 | 25153 | -- | -- | .381 | 9583 | 11500 | 534 | 12034 |
| 1959 | 29459 | -- | -- | .385 | 11342 | 13610 | 539 | 14149 |
| 1960 | 49757 | 2,853000 | 1107213 | .388 | 19306 | 23167 | 593 | 23760 |
| 1961 | 61845 | -- | -- | .391** | 24181 | 29017 | 636 | 29653 |
| 1962 | 71061 | -- | -- | .395** | 28069 | 33683 | 676 | 34359 |

* Interpolated
** Extrapolated
# Calculated

In this figure, projections C and D contain the envelope of boat population growth in Seattle and vicinity through 1970. It must be noted that the curves for Washington state and for Seattle are not exactly comparable since the one is based only on registered plus documented craft while the other is based on adjusted registered craft plus documented craft. Nevertheless it is obvious that the curves are quite similar which is some justification for the mathematical approach used.

The projections of future growth indicate that in the year 1970 there will be between 61,000 and 78,000 powered pleasure craft in greater Seattle.

## Composition of the Boat Population

At this point, a word should be said concerning the composition of Seattle's boat population. A knowledge of the precise composition (length, propulsion, etc.) of this boat population would be desirable later in this paper. For this, the author employed the 1963 yearbook of the Seattle Yacht Club (8). This publication lists all vessels belonging to members of that organization, and includes various data such as length, radio call letters, type, racing class, etc. This listing has the virtue of including both vessels moored in the water and vessels stored on trailers.

Table 4 contains information on the composition of Seattle's boat population based on these data.

Four basic categories of pleasure craft were considered: outboard motorboats, inboard motorboats and cruisers, small sailing craft (arbitrarily defined as sailing craft 22 feet or less in length), and large sailing craft. The total number of pleasure craft listed was 952. The breakdown of these craft into the four categories considered, the percentage of the total number of vessels in each category by number, the average length of vessels in that category and the percentage of the total number of vessels in that category by length are summarized in Table 4. In addition the number and percentage of vessels carrying marine radios are shown.

The author feels that this represents the best compositional information available short of a very ambitious statistical survey program. It must be realized that because of the income bracket to which most members of the Seattle Yacht Club belong, this compositional information is almost undoubtedly biased in favor of a larger, longer and more expensive vessel. Since all other calculations and results developed in this report will probably be on the conservative side of the true figures, a combination of those calculations with these compositional figures may well be mutually compensatory.

## Factors Affecting Traffic in the Ship Canal System

The availability and advantages of the great expanse of fresh-water moorage space in the greater Seattle area has tended to concentrate by far the greater portion of the vicinity's boat population into inland areas.

## TABLE 4

## COMPOSITION OF THE BOAT POPULATION-SEATTLE, WASHINGTON

| ITEM | MOTOR CRAFT | | | SAILING CRAFT | | | ALL TYPES |
|---|---|---|---|---|---|---|---|
| | OUTBOARD | INBOARD | TOTAL | SMALL (UNDER 22') | LARGE (Over 22') | TOTAL | |
| **Number** | 111 | 521 | 632 | 105 | 215 | 320 | 952 |
| No. with radios | -- | -- | 300 | -- | -- | 60 | 360 |
| Total Lengths, ft. | 1930 | 20,210 | 22,140 | 1837 | 7689 | 9526 | 31,666 |
| Av. Length, ft. | 17.4 | 38.8 | 35.0 | 17.5 | 35.8 | 29.8 | 33.3 |
| % of Total by No. | 11.7 | 54.7 | 66.4 | 11.0 | 22.6 | 33.6 | 100.0 |
| % of Total by Lgth. | 6.1 | 63.8 | 69.9 | 5.8 | 24.3 | 30.1 | 100.0 |
| % of Total with radios | -- | -- | 47.5 | -- | -- | 18.8 | 37.8 |

Simultaneously, the proximity of these moorage areas to Puget Sound causes many boat-owners to seek less restricted waters for their pursuits while maintaining their moorage in fresh-water. In addition, a certain proportion of those yachtsmen who moor their craft in salt-water moorages occasionally find reason to navigate the ship canal system to Lake Washington. The intensity of this traffic is influenced by a number of factors. The most readily understandable of these are cost of moorage, cost of maintenance and convenience in and to the various mooring areas.

The primary factor favoring salt-water moorage is one of convenience. The yachtsman who prefers to sail Puget Sound and its approaches and in Pacific Coastal waters rather than the inland areas of Lake Washington and Lake Union may well prefer a mooring site directly situated on Puget Sound. In addition, yachtsmen who live near a salt-water facility may prefer that facility due to proximity alone. Another factor which is reputed to have enhanced the desirability of salt-water moorage is the increasing congestion of Lake Washington with cross-state highway bridges which are making suitable yacht racing areas increasingly scarce on the lake. There is a current trend towards the shifting of yacht-racing activities from the interior out to the Sound. With existing facilities there becoming the center of these activities, competitively minded yachtsmen may prefer the additional convenience of mooring near the hub, or future hub, of sail racing activities.

The very congestion under study in this thesis may eventually be the most powerful factor influencing yachtsmen to move their moorage to salt-water.

In spite of this congestion however, owners of marinas in fresh-water may be seen to be expanding their facilities at a rapid rate to satisfy the demand for additional service in these areas. The already heavy concentrations of traffic in fresh-water tends to induce concentrations which are heavier yet.

The two principal disadvantages of salt-water moorage are increased exposure to the elements and exposure to damage by corrosive action and the action of marine organisms, both fouling and boring. Not only does moorage adjacent to Puget Sound expose a craft to the greater severity of weather to be experienced in less protected areas, but by far the majority of on-sound moorages are uncovered, posing a serious problem to the boat owner whose craft is not completely weather-tight. This objection is only applicable to power cruisers since sailing craft find covered moorage impracticable due to mast height, and very small craft find it too expensive.

Puget Sound has its share of boring organisms. These are a particularly serious problem to the owners of wooden-hulled craft. Even so, vessels of this type may be even now observed in salt-water moorage facilities. Since the majority of modern pleasure craft are being built of metal or of fiberglass and other plastic laminates which are not attacked by boring organisms, the generality of this disadvantage will decrease as older, wooden hulled vessels are retired from service.

The problems of electrolytic corrosion and fouling organisms in salt-water are of course applicable to every type of vessel.

Even the most modern methods cannot entirely obviate electrolytic corrosion of metal hulls, propellers and hull and super-structure fittings. Fouling organisms also seem to have no particular aversion to any sort of hull unless thoroughly treated with an anti-fouling paint.

Considering both protection from the elements and reduction of maintenance, most yachtsmen find fresh-water moorage highly desirable. Since most boring and fouling organisms cannot live in fresh water, these problems are almost entirely eliminated. Hulls must be beached only at great intervals in order to remove fouling plantsgrowths. The annual beaching required of salt-water moored vessels is not encountered by the fresh-water yachtsman. The high rate of availability of covered moorage in Lake Union, Portage Bay and Salmon Bay makes moorage in fresh-water areas highly attractive to those yachtsmen who desire the added protection conferred by covered moorage and whose craft can be accomodated in this manner. Many yachtsmen consider covered moorage an absolute necessity in view of general weather conditions in the Seattle area. The more protected inland location is desirable even for weather-tight craft and for those who cannot, or choose not to make use of covered moorage. Obviously, the salt-water corrosion problem is completely non-existent.

The convenience and cost are two other factors that may affect the yachtsmen's choice of one type of moorage in opposition to another, and thus will influence traffic patterns. At present there is no significant difference in basic cost between salt-water and fresh-water moorage in Seattle.

Salt-water moorage is on the average cheaper but this is due to the fact that virtually all salt-water moorage now in existence is uncovered; it is no cheaper than is uncovered moorage in inland areas.

Those yachtsmen who reside near the lakes may prefer to moor on the lakes and their connecting waterways. This would be particularly true of those yachtsmen living in the municipalities bordering the eastern shores of Lake Washington. Yachtsmen living in areas having convenient access to salt-water may prefer moorage there and of course, the increase in cross-lake bridge facilities may result in an increased use of salt-water moorage by yachtsmen from more easterly areas.

Access to salt-water is obviously no problem to those who are already moored there, but for those yachtsmen who choose fresh-water moorage, the problem of access through the Hiram M. Chittenden Locks is undoubtedly the most significant convenience factor involved. Long waits at the locks may represent a large loss in utility to yachtsmen who annually invest many thousands of dollars in owning and maintaining their craft, with the return of only a few hours of use per week. Certainly if this lost utility (due to congestion at the locks) surpasses the additional maintenance costs that might be expected in salt-water, one might expect a fresh-water yachtsman to shift his moorage outside of the congested inland area.

One of the principal factors affecting traffic pattern development in Seattle's recreational waterways is the number and location of facilities catering to pleasure craft that exist therein. Existing pleasure boat moorages are sited in Lake Washington, Portage Bay, Lake Union, Salmon Bay, Shilshole Bay Elliot Bay and the Duwamish River waterways.

The author estimates that there are about 6000 berths presently available in fresh-water and 2500 in salt-water.

For those craft which are launched and retrieved each use being stored on land on a boat trailer in the interval between usages, the location and convenience of boat launching ramps is a major contributing factor. The trend here parallels that of other pleasure boating facilities in the area, the majority of available boat launching ramps being located adjacent to fresh-water. No available statistics indicate effectively the variation between water and land based pleasure craft traffic patterns. Until evidence to the contrary is available, it is reasonable to assume that traffic patterns generated by shore based pleasure craft parallel those that exist for the boat population in general.

# CHAPTER II

# OPERATIONS AT HIRAM M. CHITTENDEN LOCKS

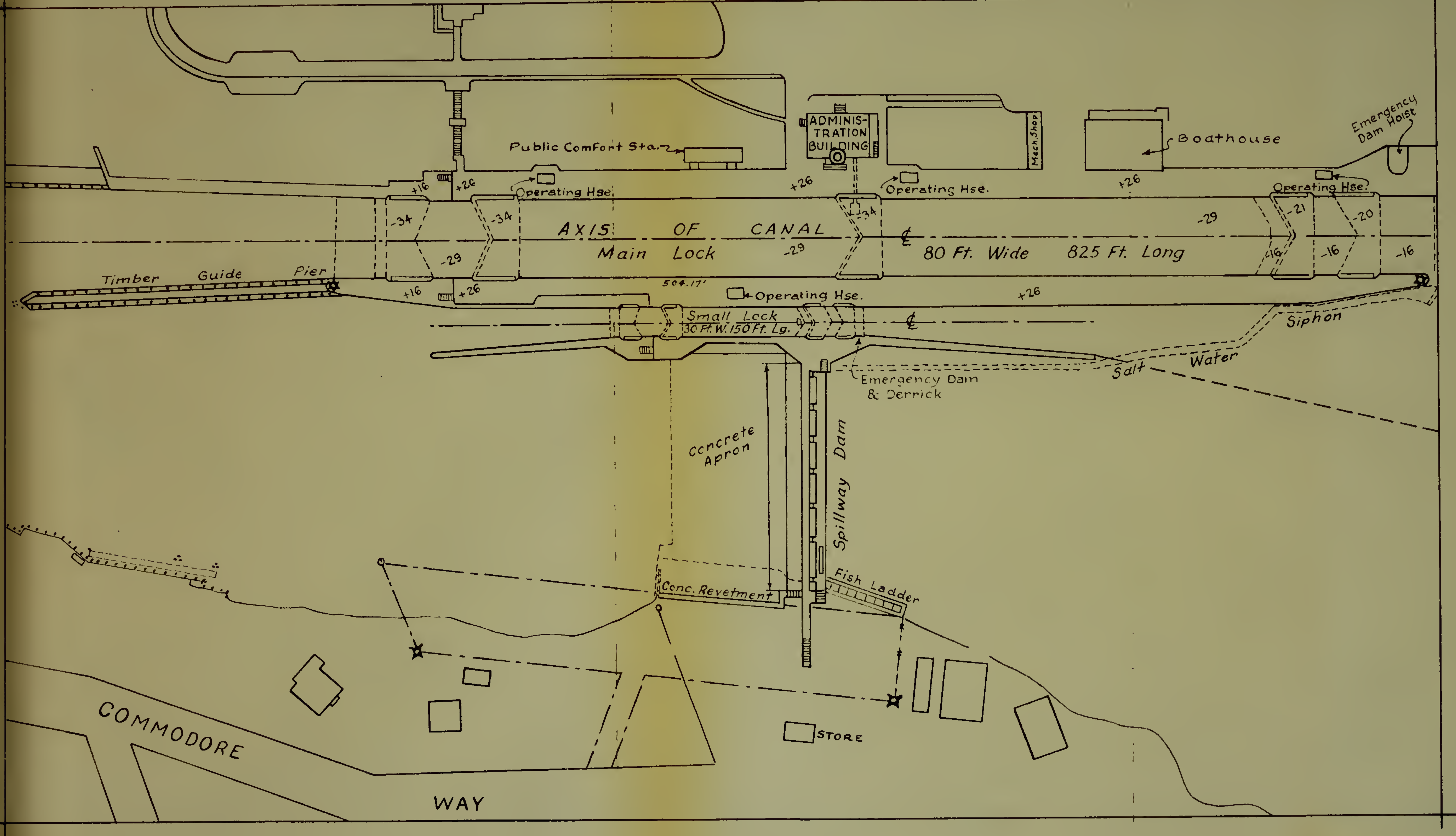
## Layout and General Description

The general layout of Hiram M. Chittenden Locks is illustrated in Figure 4. The lock complex consists of three basic components; the large lock, the small lock and the dam that maintains the water level in the inland lake complex. Figure 5 shows a section through the dam and various pertinent data are listed in Table 5.

Before the construction of the locks and dam there not only was no connection between Lake Union and Puget Sound, but also there was no connection between Lake Washington and Lake Union. The water level in Lake Washington was naturally regulated between elevations of 29 and 33 ft. above mean tidal level in Puget Sound, its outlet being at the southern end of the lake via the Black and Duwamish rivers. Lake Union was regulated artificially at more or less its present level by a spillway at the western end of the lake. Salmon and Shilshole bays were tidal waters.

During the construction of the present ship canal complex, a channel was dredged through Shilshole Bay to make it navigable at all times. Lake Washington and Salmon Bay were lowered and raised respectively to match their levels to that of Lake Union. The connecting passages between Salmon Bay and Lake Union, and Lake Union and Lake Washington were dredged to navigable depth and the locks and dam installed in their present location.

FIGURE 4 – HIRAM M. CHITTENDEN LOCKS – GENERAL PLAN



## TABLE 5

## HIRAM M. CHITTENDEN LOCKS - DATA AND DIMENSIONS

### MAIN LOCK

| | |
|---|---|
| Available length | 760 ft. |
| Available length, east chamber | 385 ft. |
| Available length, west chamber | 327 ft. |
| Depth on upper mitre sill at low water | 36 ft. |
| Depth on lower mitre sill at mean lower low water of Puget Sound | 29 ft. |
| Width | 80 ft. |
| Height of wall above floor of lock | 55 ft. |

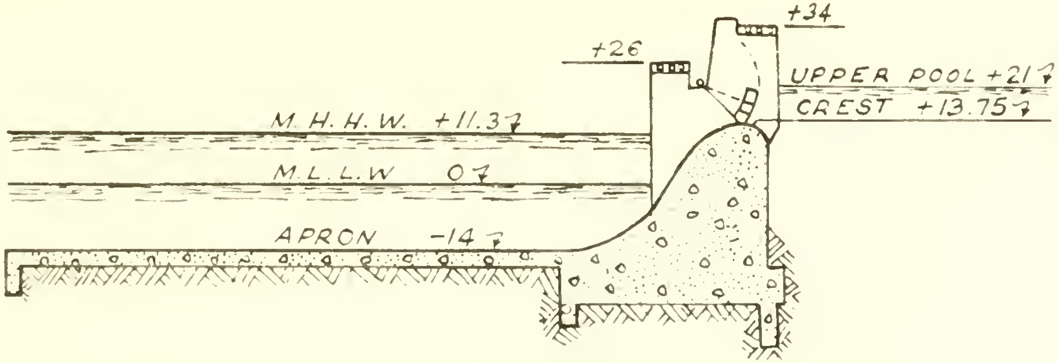
### SMALL LOCK

| | |
|---|---|
| Available length for square ends | 123 ft. |
| Depth on upper mitre sill at low water | 16 ft. |
| Depth on lower mitre sill at mean lower low water of Puget Sound | 16 ft. |
| Width | 28 ft. |
| Height of wall above floor of lock | 42 ft. |

### WATER LEVELS

| | |
|---|---|
| Upper Pool | |
| Maximum level | +22.0 ft. |
| Minimum level | +20.0 ft. |
| Range | 2.0 ft. |
| Lower Pool | |
| Maximum high tide above datum | +15 ft. |
| Minimum low tide below datum | -4 ft. |
| Extreme tidal range | 19 ft. |

# SECTION THROUGH DAM – HIRAM M. CHITTENDEN LOCKS



SECTION THROUGH DAM

FIGURE 5

The entire inland waterway complex is now regulated by this one dam at a level of from 20.0 to 22.0 feet above tidal datum.

The variation in size between the large and small locks is an indication of the relative importance attached to commercial as compared to pleasure boat traffic at the time the locks were constructed, the large lock being over six times as long and very nearly three times as wide as it smaller counterpart. It is noteworthy that the larger lock is divided in two by a set of central gates, thus simultaneously providing a large capacity and an intermediate capacity lock.

The distance through this system from deep water in Puget Sound to deep water in Lake Washington is about eight miles. Since tides in Shilshole Bay have a range of about 19 feet, varying from 4 feet below datum to about 15 feet above, vessels passing through the locks are lifted or lowered between 6 and 26 feet depending on the state of the tide and the water level of the lakes.

The United States Army Corps of Engineers claims that an average transit through the large lock requires about 25 minutes and through the small lock about 10 minutes. Large ships, they say, seldom require more than 30 minutes. Tows occasionally take an hour but usually pass through in about 30 minutes. They estimate that about 30 pleasure craft can be accomodated along the walls of the large lock but if they are moored several abreast, about 60 can be taken at a single lockage (7).

## Description of Lock Operations

The demand for passage through the locks reaches its peaks only during the daylight hours of weekend days and holidays in the summer months. Throughout most hours of most other days, traffic demand are light.

Under these circumstances of light traffic flow, vessels arriving for passage through the locks are routed to the lock appropriate to the size of the vessel. If any of the dimensions of a vessel exceed the maximum of 70 feet of length, 24 feet of width, 10 feet of draft and 42 feet of height above the waterline, the vessel is routed through the large lock. All smaller craft are routed through the small lock. The number of pleasure craft that exceed these maximum dimensions is quite small, being limited to very large motor and sailing yachts. To say that by far the majority of all pleasure craft are of a size permitting passage through the small lock would be understating the case. Virtually all pleasure craft may use this smaller facility if no other consideration enters the picture.

Under some circumstances, small craft may be routed through the large lock even in times of low traffic flow. Whenever the large lock must be cycled in order to accomodate some vessel exceeding the previously stated dimensions, as many smaller craft as are in the vicinity are admitted to the large chamber and locked through simultaneously.

To summarize this pattern of off-peak operations we may say that vessels exceeding certain stated minimum dimensions are routed through the large lock while all smaller vessels are routed through the small lock with the exception that whenever the gates of the large lock are opened for a large vessel, any small craft standing by are admitted to the large lock and cycled through in company with the large craft.

## High Density Traffic Patterns

During those hours of those days on which pleasure boatmen are most avidly pursuing their nautical interests, large numbers of small craft present themselves at the locks for passage to one side or the other. As the rate of arrival of such vessels increases, eventually exceeding the maximum practical traffic handling capacity of the small lock, a line (or queue) of vessels awaiting lockage builds up along the small lock waiting pier and in the holding areas above or below the locks.

During these peak times the large lock must be pressed into service in order to handle the great numbers of craft demanding passage. As a matter of practical interest, on days favorable to yachting, the capacity of the small lock is exceeded at about 10 a.m. From this time on the small lock is cycled as rapidly as possible, transferring a full chamber load each cycle, while excess traffic is routed through the larger lock.

In times of relatively high density of traffic at the locks, several characteristic conditions develop. The time required for a single lockage (hereafter referred to as a transit) through either lock increases considerably over that required during off-peak hours. In the small lock, the time necessary for a transit may increase from the minimum of 5 or 10 minutes to as much as 25 or 30 minutes.

This same lengthening of the transit time occurs in the large lock to an even greater, and for the purposes of this thesis, much more significant extent. In this lock, the time required for a passage increases from the off-peak minimum of 10 or 20 minutes to an hour or even longer.

## Queueing Patterns

Once the transitional phase separating the characteristic operational patterns of low from high traffic density has been passed, queueing vessels will have filled the waiting piers for both large and small lock, the remainder forming a large pool of craft maneuvering and lying-to in the holding areas above or below the locks. Boats in these queues are the boats that are waiting to be admitted to one of the locks when the gates are opened again. As soon as one of the locks is full, the gates are closed and the operation of lifting or lowering is performed. All craft arriving at that lock after the gates are closed must wait through a cycle of lift and lower before the gates can be re-opened and they can be admitted.

It is when the queue waiting for entrance to the small lock becomes longer than the capacity of the lock for the next transit, that the gates of the large lock are opened and it also is pressed into service.

In general these queues or waiting lines are not allowed to develop to an extent where there are more vessels waiting for use of the lock than can be handled during the next transit in both locks. On some very high traffic days this does in fact happen, usually in the evening and to that traffic returning into Lake Washington after the week-end's yachting. From the standpoint of this thesis, the point of salient interest is that many pleasure craft which would otherwise be able to pass through the small lock must instead use the larger facility, experiencing the much longer transit time associated with it, and may in fact have to wait one or more full cycles of that lock for passage.

It is worthy of note that although queueing is the most obvious characteristic of the congestion problem at the government locks, the mathematics of "queueing theory" are not usuable in determining the parameters of the congestion since records kept at the locks indicate only the number of vessels passing through and contain no indication either of arrival rates or of queue dimensions.

## One Way Traffic

One point that has not been covered yet but which is essential to understanding of the traffic patterns occurring during congested times is the one-way character of arrivals at the locks.

Most yachtsmen want to leave their fresh-water moorings and transit the locks to salt-water sometime during the morning or early afternoon. These same boatmen usually want to return inland of the locks sometime in the late afternoon or early evening. These desire trends give rise to traffic patterns which are characterized by extreme directionality. Traffic flow is principally seaward in the morning and early afternoon and principally lakeward in the late afternoon and evening, the traffic flow in directions opposite to this trend being very nearly insignificant in amount.

## Prediction of Lock Arrivals

It was demonstrated in the previous chapter that the popularity of boating and the number of pleasure boats in existence is increasing rapidly in the nation, the state and in Seattle itself. At present, the majority of all pleasure craft in Seattle and vicinity are concentrated into the fresh-water moorages inland of the Hiram M. Chittenden Locks. The desire of many yachtsmen to pass frequently through the locks and into Puget Sound and then to return to fresh-water moorage has created a condition of severe traffic congestion in the ship canal system in general and specifically at the locks themselves. It is certainly reasonable to assume that Seattle will follow the general trend of increase in the popularity of boating; and as the boat population increases (and as was shown in Figure 3 we may expect the boat population of Seattle to very nearly double within the next six years) the demands on the locks for passage to and from Puget Sound and inland waters will become greater and greater.

In Table 4 are summarized data adopted from records kept by the United States Army Corps of Engineers at the Hiram M. Chittenden Locks. The number of pleasure craft and other vessels using the locks annually and the total of these two are tabulated for the years 1953 through 1963. Figure 6 is a graphical representation of this data showing the annual variation of pleasure traffic, traffic attributable to types of vessels other than pleasure craft, and the total traffic through the locks.

These curves indicate a number of notable features characteristic of the traffic through the locks. Notice first of all that the volume of pleasure craft traffic has, since 1953, grown to where it is considerably greater than the volume of all other traffic combined. Notice too, the similarity in shape between the pleasure craft curve and the curve for all vessels through the locks. The implications here are first that pleasure traffic is far and away the most important type of traffic passing through the locks as far as numbers of craft involved and secondly that the total traffic handled in a year varies as the pleasure traffic for that year varies. Minor details noticeable are the peak in commercial traffic and accompanying peak in total traffic caused by the opening of the Shilshole Bay Marina in combination with the business recession of 1959-60.

The dashed lines in Figure 6 are projections indicating the future traffic volumes that may be expected through the locks. In making these projections the 1962 World's Fair peaks were ignored. These projections indicate that by 1970 commercial traffic will have again reached a volume of more than 30,000 vessels per year, falling about 2,000 vessels short of matching the 1962 peak.

## TABLE 6

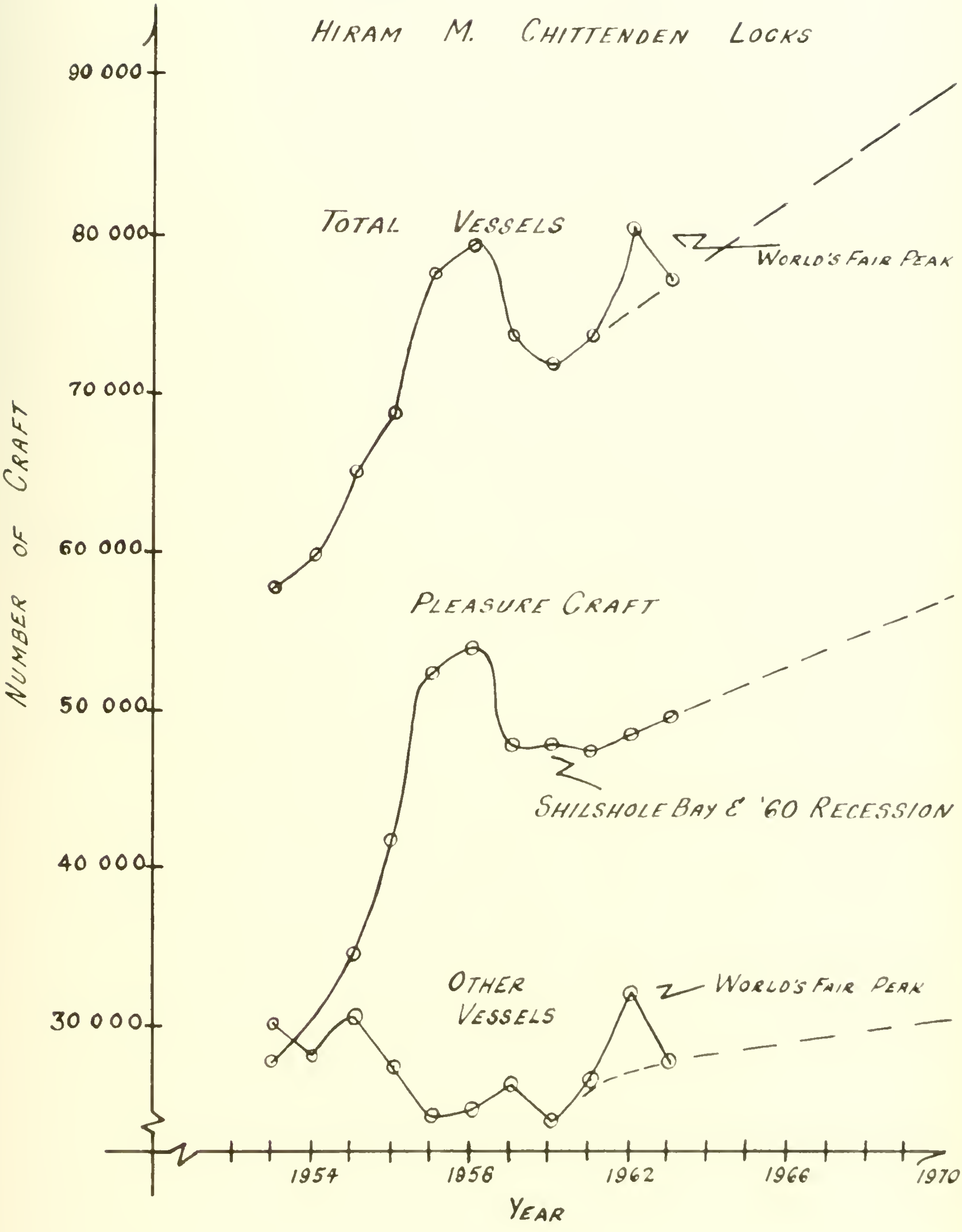
## SUMMARY OF VESSELS PASSING THROUGH HIRAM M. CHITTENDEN LOCKS

| YEAR | PLEASURE* CRAFT | OTHER VESSELS | TOTAL |
|---|---|---|---|
| 1953 | 27,721 | 30,066 | 57,787 |
| 1954 | 31,766 | 28,009 | 59,775 |
| 1955 | 34,640 | 30,291 | 64,931 |
| 1956 | 41,551 | 27,031 | 68,582 |
| 1957 | 52,221 | 25,115 | 77.336 |
| 1958 | 53,883 | 25,513 | 79,396 |
| 1959 | 47,679 | 26,011 | 73,690 |
| 1960 | 47,822 | 23,937 | 71,759 |
| 1961 | 47,059 | 26,341 | 73.400 |
| 1962 | 48,270 | 31,965 | 80,235 |
| 1963 | 49,401 | 27,612 | 77,013 |

*Includes pleasure craft of foreign origin.

FIGURE 6

NUMBER OF PASSAGES THROUGH HIRAM M. CHITTENDEN LOCKS



Pleasure traffic should increase steadily, surpassing the 1958 peak by 1967 and reaching a level of over 57,000 vessels per year by 1970. Barring major fluctuations in the national economy then, total traffic volume through the locks will have reached an all time high by 1965 and will amount to more than 88,000 vessels per year by 1970. This will be an increase of 8,000 vessels per year over the 1962 record of 80,000. This means that we may expect an increase of 10% in traffic through the locks within the next six years. This is considerably less than the 60% increase in the overall boat population that may be expected within the same period. Nevertheless, considering the state of congestion that exists under present traffic loads, an increase of even 10% may well prove intolerable.

# CHAPTER III

# POSSIBLE MEANS OF REDUCING CONGESTION

Possible means of reducing congestion in the Lake Washington Ship Canal and Hiram M. Chittenden Locks fall into two general categories; those measure which would reduce congestion by increasing the actual physical capacity of the locks and those measure which would attempt to reduce congestion by inducing decreased peak traffic volumes, spreading this traffic out over a longer time period. Of all conceivable methods of reducing congestion in the locks and the ship canal system, only a few can be subjected to any sort of analysis at all. This thesis will confine itself to one or two of the most promising of these. It is desirable however to mention and tabulate as many methods and proposals for reducing congestion as possible simply to provide a basic working list from which the most promising proposals can be selected.

## Education and Information

It is possible that some reduction in congestion and in travel time through the locks might be achieved by information and educational programs designed to better acquaint yachtsmen with lock rules and procedures. Acquainting Seattle boatmen with the general trend of traffic patterns at the locks would enable them to choose off-peak times for transit. Such programs could be effected by publishing pamphlets of lock rules and lockage data and procedures showing what hours are most favorable to expedient passage through the locks, distributing them to

yacht clubs and to vessels passing through the locks. Using these publications as an aid, personnel of the United States Army Corps of Engineers and Coast Guard could conduct instruction at various yacht clubs and marinas in proper procedures and lock seamanship. In actuality, sheets listing lock rules and procedures are passed out at the locks already and the author doubts that even if some decrease in congestion could be realized by such a program, such a reduction would be great enough to compensate for traffic peaks of the magnitude we are likely to encounter in 1970.

### Administration

In order that proper records may be maintained of the number and type of vessels and cargoes passing through the locks, each vessel must fill out and submit a form containing various pertinent information. When there are sixty small-craft involved in a single lockage through the large lock, the distribution, filling out and collection of these forms may become time-consuming. As a matter of fact a considerable portion of the increase in time required for a single transit through the locks is attributable to administrative details involving lockage records. In order to streamline administration as much as possible, the United States Corps of Engineers personnel distribute quantities of lockage forms to the owner of vessels passing through the locks so that they may have a supply of these forms on board and can have them properly filled out prior to arriving at the locks. Even so, a large number of boat owners

must be individually supplied with the proper form and the form filled out and collected before each transit can be completed. In addition to this, the distribution, collection and tabulation of these forms is a burden on the lock masters and their assistants and on lock personnel in general.

One improvement in this situation might be made by establishing automatic lock-form dispensers at a considerable distance upstream and downstream from the locks so that yachtsmen intending to pass through the locks and not having a form on board might provide themselves with these forms and fill them out prior to arriving at the locks. It would then be necessary to furnish forms at the locks only to those craft whose owners resolutely ignore all other distribution points.

Lock form distribution locations at the locks themselves should be installed along the lock wall as far upstream and downstream from the locks as possible. Collection of filled out lock forms should be made from craft exiting the locks rather than prior to or during lockage. Obviously, form collection would be made at the same locations as form distributions. Under this system, a craft approaching the locks, even if not already provided with a form, could pick a form up before entering the locks, have at least a quarter of an hour to fill it out, and then hand it in upon exiting from the lock.

The effect of such a system upon lock operation is somewhat unpredictable. It might result in a great saving in travel time, or the saving might be only insignificant. The only adequate way of determining this is experimentally by actually putting such a system into operation, for say, the small locks.

Another approach of the same sort would be the complete automation of all lockage records. Automatic radar traffic counters of the type presently used to control traffic lights could be installed to keep check on the number of craft passing through the locks. In addition, those craft which are frequent users of the locks could be provided with punched or magnetically sensitized cards which, when inserted into reading devices positioned at frequent intervals along the lock walls, would automatically supply all information that must presently be listed by hand. Whether or not such an automated system would reduce transit time, thereby decreasing congestion is a matter for debate. There is some doubt that it would take any less time to insert a magnetic card into a reading device than it would take simply to hand in a previously filled out form of the type now in use. There are however, many advantages which would accrue through the use of such a system, some of which will be discussed later. These advantages are outside the realm of congestion and travel-time consideration and are properly the subject for consideration by experts in automation rather than being subject matter for this investigation.

## Continuous Traffic Flow Information Systems

One other approach to the reduction of traffic volumes in the ship canal and at the locks would be to continuously inform yachtsmen of the degree of congestion currently existing there. This could be done by means of radio broadcasts on marine frequencies, by continuously informing yacht clubs and marina by telephone or by use of indicating devices situated at appropriate locations in the ship canal system.

In Chapter 1, when the composition of the boat population in Seattle was investigated, it was discovered as a by-product of this investigation that 37.2% of the craft considered in this investigation carried two-way marine radios and it was assumed that a certain additional percentage would have receivers capable of receiving marine frequencies. These craft would all be capable of receiving continuously or intermittently broadcast information concerning traffic conditions at the locks. The recipients of such information might then decide whether to continue on through the locks immediately or to delay their transit until a more appropriate time. The general effect would be to spread traffic over a greater period of time.

There are several objections to this plan. Even if 50% of all boats using the ship canal carried radios, only some smaller percentage of these would actually have them energized. This would mean that broadcasts on marine frequencies would not reach by far the larger percentage of all craft using the canal. Receivers might be installed at marinas and yacht clubs to receive the appropriate frequency continuously but this would be no more effective than informing these same facilities of traffic conditions by means of telephone. It is also worthy of note that most marine frequencies have a much more important use than as a carrier of traffic condition information.

Telephone information, while available to those yachtsmen based at a marina or yacht club interested in participating in a telephone information system, would not be available to craft that had already departed for their moorage or launching site. Visual traffic indicators established in Shilshole Bay, Salmon Bay, Lake Union, Portage Bay and Union Bay might prove to be one of the more useful informative devices. These indicators could be

electrically operated by remote control, over telephone cables laid from the locks to the indicators. One form of such an indicator might be a clock-faced dial indicating the estimated number of minutes it will take to pass through the locks at the current degree of congestion. A separate hand could be used for the large and for the small lock and to make the display even more graphic, the dial could be color coded green for good conditions, orange for intermediate and red for congested conditions. An artist's conception of such an indicator is shown in Figure 7.

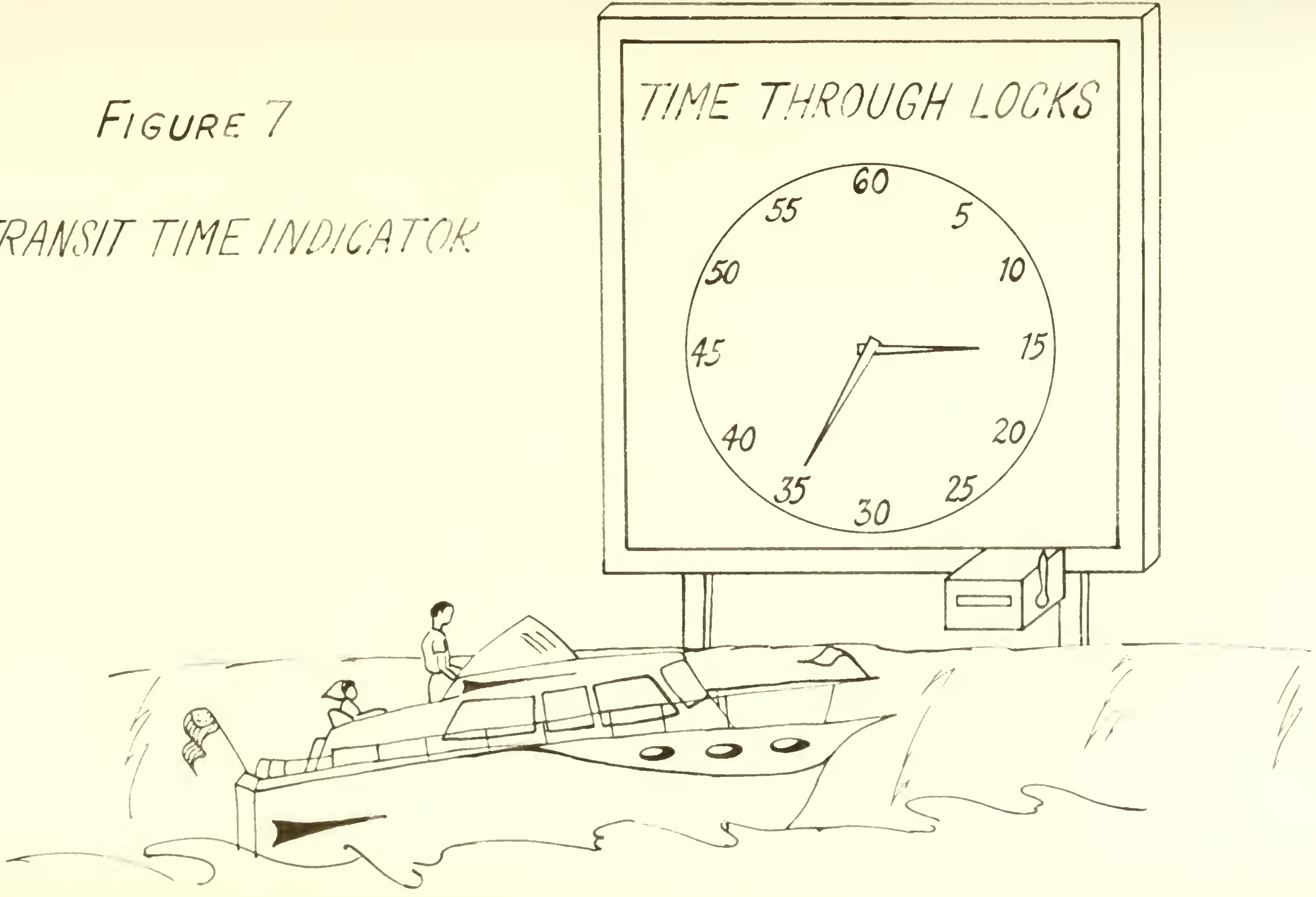
This type of visual indication, while more expensive than any of the schemes previously mentioned, would have the advantage that it would contact all yachtsmen using the ship canal system and not just those tuned to a particular marine frequency or those who had just departed from a yacht club or marina. The automatic lockage form dispensers mentioned previously could be located in the vicinity of these indicators. If an indicator system such as this were established, it would be a simple matter to extend the required transmission lines to interested marinas and clubs, installing smaller indicators directly at these facilities. Unfortunately, although such an indicator system is an intriguing possibility, the author can think of no way to investigate its economic feasibility or to predict its effect in reducing congestion at the locks.

## Measures to Increase Rate of Traffic Flow

In addition to the fact that none of the measures so far discussed are susceptible to detailed analysis, they don't really solve the problem anyway. They simply make the problem appear to be less severe.

FIGURE 7

TRANSIT TIME INDICATOR



All these previously mentioned measures were intended simply to spread traffic over a greater period of time, thus reducing the intensity of peak traffic loads at the locks. This spreading of the peak must inevitably be accomplished by causing yachtsmen to advance or delay their departure from their moorage or launching ramp or to delay at some intermediate facility while awaiting a more favorable time. We have not however, eliminated the disutility caused by congestion. The disutility experienced by a yachtsman who delays or even cancels his transit of the locks may be even greater than the disutility he would have experienced due to delays and congestion at the locks themselves. The only positive method of obtaining reductions in travel-time and positive relief of congestion at the locks is to actually increase the rate at which vessels can pass the locks. The author can visualize three basic approaches to accomplishing this intent: by modifying the existing locks in such a fashion as to increase the rate at which they can handle traffic; by establishing a conveyor belt or a marine railway which would enable pleasure craft to pass from lake level to sea level without actually passing through the locks; or by building one or more additional locks.

## Modifications to Existing Locks

There would seem to be relatively few conceivable modifications possible to the existing locks. Such modifications might include lengthening either or both existing locks in order to increase their total capacity, modification of the hydraulic mechanisms involved in the transfer of water into and out of the lock chambers, and modifications of a sort intended to

facilitate seamanship and administrative procedures.

The first of these that we will consider will be modifications to the existing hydraulic systems. Later in this report data will be presented which will show that with their presently installed hydraulic systems, the large locks are capable of a minimum lift time of about 10 minutes; while the small locks can be emptied or filled in a minimum of about 5 minutes. Even now there is some complaint among yachtsmen of turbulence in the lock chambers. The present hydraulic system in the locks is quite massive. For instance, the main water transfer culverts of the large lock are $8\frac{1}{2}$ feet wide, and 14 feet high. The laterals which extend from these culverts into the lock chamber are 4 feet wide and 2 feet high.

In comparison to minimum transit times of 5 and 10 minutes for the small and large locks respectively, the maximum transit times are as much as 20 minutes in the small lock and 60 minutes in the large lock. This great increase in the time required to complete a trip is a combination of the time necessary for vessels to enter the locks, moor along the lock walls, receive, fill out and return lockage forms, be lifted or lowered, unmoor and evacuate the locks. In actuality all time over and above the minimum transit time is consumed in boat handling and administrative matters.

It is the author's belief that even if the existing massive hydraulic system at the locks could be modified in such a way as to reduce the transit time, the paring of one or two minutes off that portion of the transit time occupied in hydraulic operation would not significantly influence the overall time required for a trip through the locks during

peak traffic hours. For this reason, investigation of possible modifications to the existing hydraulic system is not considered worthwhile and will be excluded from consideration herein.

Since the majority of the time spent in lifting and lowering vessels during peak traffic hours is spent in boat handling and in administrative functions, any measure that would speed up these operations would reduce the time required for a transit of the locks, thus increasing the traffic handling capacity of the existing installation. Proposals pertaining to administration have been discussed in preceding portions of this chapter.

The only modification that might tend to speed up boathandling at the locks would be the installation in the large lock of floating fenders of the type currently in use in the small lock. Such fenders, rising and falling along with the water level in the lock chamber and providing moorage attachments, reduce the amount of linehandling involved in passing through the locks. Installing fenders of this sort in the large lock would reduce the available width from 80 feet to about 74 to 76 feet. Whether or not such a decrease in the available width of the lock is justifiable in view of the disadvantages it would occasion to commercial traffic, the author does not know. In fact the author has no idea, whether installation of floating fenders in the larger lock would affect boat handling procedures there enough to produce a significant decrease in maximum transit times, nor can he conceive of any rational attack on this particular problem of other than an experimental nature. If the installation of floating fenders in the large lock should

ever be considered it might be possible to gather data on the desirability of this move by noting the increase in cycle length occasion when boats passing through the small lock were forbidden to use these fenders. With this data in hand, undoubtedly some sort of an approach could be made to determine if such an installation in the large lock would be justified.

The final type of modification of existing lockage facilities which will be considered will be that of increasing the length either of the present large lock or of the small lock or both. The author does not consider any such increase in length either desirable or justifiable, or even to be a valid line of attack on the problem. In fact, none of these alternatives will be included in the numerical analyses which constitutes the latter portion of this report. Some justification however, must be made for this exclusion.

There are several factors which militate against the feasibility of increasing traffic capacity by increasing the length of the present locks. One of these is cost. It is very likely that it would be just as expensive to increase the length of the present locks as it would be to provide an additional lock having the same capacity; whereas the increase in length would not provide the flexibility of operation that would be provided by an additional separate facility. Also to be considered is that the minimum transit time would be increased. If either of the locks were lengthened, other dimensions remaining the same as at present, the increase in water required for a lift or lowering would be exactly proportional to the increase in length. Earlier it was seen that the already

small minimum transit times could probably not be reduced significantly by increases in the water handling capacity of the hydraulic system. This situation would not now hold true. While it is not certain that the increase in minimum transit time would be exactly proportional to the increase in length, these times would doubtlessly increase significantly. In addition, since the number of additional vessels that could pass through the locks during a transit would be more or less proportional to the increase in length, boat handling and administrative problems would also increase just exactly this much. The net result would be that the maximum transit time would probably rise more or less in proportion to the increase in capacity. The result of this would be that not only would total traffic handling capacity not be increased, but that the actual total vessel-hours of travel time required for passage would be enlarged rather than reduced.

When we increase the length of the small lock, what we are doing in effect is to convert it from a "small" lock into an "intermediate" lock. What is the point in doing this when two different sizes of intermediate lock are in fact already available due to the placement of the center gates in the existing large locks? As a final word on the unfeasibility of lengthening the present locks, consider the following proposition: replace the present locks with a dam and single lock gate at the Shilshole Bay end of the ship canal and a dam and single gate at the Lake Union end of the canal. We would now have a lengthened lock chamber capable of holding several thousand vessels. With this lengthened chamber we could accomodate an entire day's traffic simultaneously. (The greatest number of vessels ever handled in a single day was 1,189 craft on Labor Day 1957.)

The traffic handling capacity of this imaginary lock chamber would probably never be exceeded but imagine the plight of a yachtsman asked to wait a full 24 hours to complete a single passage through the locks. This is of course an extreme example, yet this is the sort of thing we are doing when we increase the length of the present locks, although on this much smaller scale the effects are not nearly so obvious. In making such an increase we would undoubtedly be increasing the capacity of the locks per transit, but we would be doing so by increasing the total transit time required to complete a passage. Increases in traffic capacity would have been gained at the expense of the user, which is precisely the opposite of the effect we are trying to achieve.

## Conveyor Belts and Marine Railways

This category includes all those devices which would increase the traffic handling capacity of the locks and reduce transit time past the locks by enabling vessels to pass directly over the dam without passing through the locks themselves. These devices constitute a valid attack on the problem of reducing congestion in the ship canal since their cost will tend to be defrayed or obviated by the benefits to the public that accrue in the form of reductions in travel time. The most serious general objection that can be brought to bear against this class of devices is that the rates at which they can handle traffic tend in general, to be rather low. An artist's conception of one such device, a conveyor belt (8) for small boats, is shown in Figure 8.

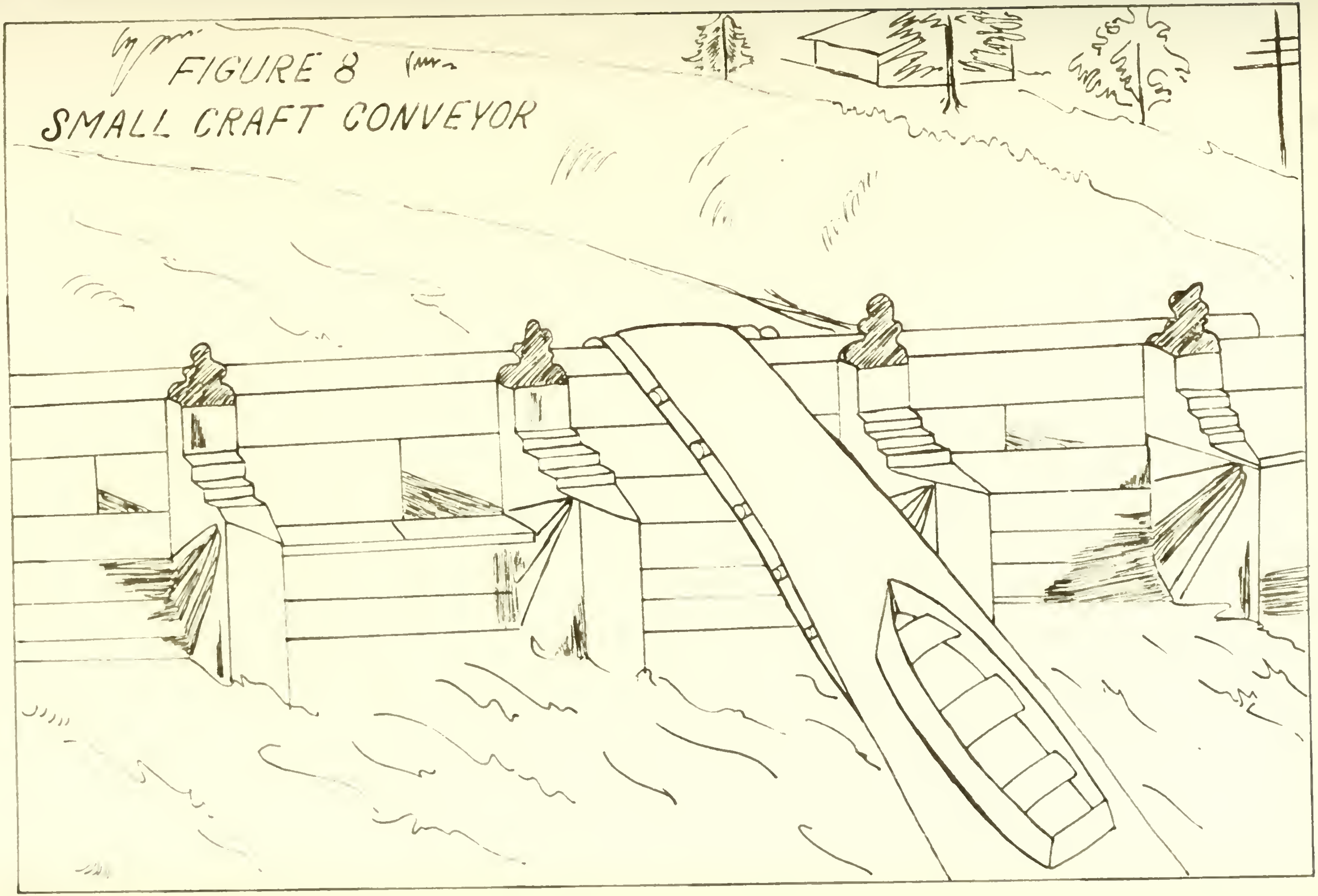


FIGURE 8
SMALL CRAFT CONVEYOR

Note in this figure that there are two lanes of traffic, one each way, that the belt slants up out of the water and over the locks and (although not shown) must pass into the water again on the other side of the locks. Any marine railway or conveyor belt system would have these general features. Provision would need to be made for traffic in both directions, subaqueous supports would be necessary either side of the dam and a center support would be necessary at the dam itself.

Marine railways (or shipways) are a traditional means of moving vessels over obstacles. A marine railway installation at the locks would employ wheeled boat-carriers (cars) running on rails. The rails would of necessity run into the water deep enough on either side of the dam that vessels could still be floated into position above the cars, even at the lowest lake level or state of tide to be expected. When a vessel is in position above a car, necessary docks would be adjusted to fit the craft and then the car and craft would be drawn up over the dam to the other side, the craft floating free again as the car passed once more into the water. Since the tracks, both up and down over the dam, would be a continuous oval, the car would then continue around and either pick up a vessel traveling in the opposite direction or be passed over the dam to the other side empty.

The most notable feature of marine railway cars is that boats are supported in them by means of chocks and pads. Since there is an almost infinite variety of hull forms, these chocks and pads must be fully adjustable and must be adjusted to fit each individual craft as it passes from aqueous support to the support of the railway car. This adjustment is a

time consuming procedure. It is difficult to conceive of a vessel being positioned over a car, the chocks and pads being adjusted and the vessel being lifted clear of the water in less than 5 minutes. Ten minutes would probably be more likely. If such were the case, the traffic handling capacity of a marine railway would then be between 6 and 12 vessels per hour either way. Since the small locks have been known to handle as many as 48 vessels per hour, a capacity of only 6 to 12 vessels per hour would seem to be rather small. Considering that at any one time the majority of traffic passing the locks is traveling in only one direction, it would require about 3 lanes of marine railway, plus one return lane, a total of 4 lanes, to match the capacity of the existing small lock. Now consider the transit time across such a facility. If it takes 5 minutes (a very conservative estimate) to adjust the chocks to a vessel and lift it clear of the water, another minute for the vessel to pass over the dam and then another minute to get the vessel clear of the railway car and floating free, a single trip would occupy about 7 or 8 minutes. This is a great improvement over the transit time experienced in passage through the large locks during times of heavy traffic and justifies further investigation of such an installation in spite of its low traffic capacity.

One other factor that must be considered about the marine railway is that it can be adapted to handle very nearly any size of vessel. Reference to Table 4 shows that the average length of pleasure craft in Seattle was a little over 33 feet. This same table shows that even among the larger classes of pleasure craft, (cruisers and large sailing craft),

the average length is under 40 feet. The suggestion implicit in this is that a marine railway could accomodate by far the majority of all craft now passing through the locks. For these reasons the feasibility of a marine railway installation will be considered as part of this thesis.

A conveyor belt (8) of the sort illustrated in Figure 8 does not have the limitation of chock and pad adjustment that was imposed upon the marine railway. This type of installation has a different limitation. Craft passing over it must be almost completely flat bottomed. Craft having large skegs, struts, screws or keels, as have inboard motor craft and most large sailing craft, could not possibly pass over a conveyor belt of the sort shown in Figure 8. Craft which could pass over such an installation would be outboard or outdrive motor boats (the motors and/or propellor units can tilt up to where they are completely out of the water) and small sailing craft (most of which have retractable center boards or leeboards).

In order to use such a facility, a motor boat or sailboat would simply maneuver until it grounded on the moving belt, was lifted out of the water, up and over the dam and back down and into the water and floated free. Boats could come onto the belt one after the other as rapidly as possible. A trip past the locks via such a device would probably occupy no more than 3 or 4 minutes, and since boats could be handled one immediately after the other, a one-way traffic capacity of as much as 60 vessels per hour could be realized.

Inspection of Table 4 indicates that outboard motorboats and small sailing craft combined total only about 23% of the total boat population.

Nevertheless this sort of an installation is considered by the author to hold enough promise to be worthy of consideration herein.

One conceivable extension of the conveyor belt idea would be a double conveyor belt with a separation between them, possible slanted in to form a V.. Such an arrangement might possibly permit transfer of inboard powered craft and larger sailing craft since the screws, struts, skegs and keels could then protrude down between the two belts. Unfortunately there is no guarantee that such a belt would support a large craft over great enough an area to prevent damage to the hull. In short, such a belt would not necessarily conform to the hull of a vee-bottomed or a round-bottomed boat in the way that a single flat belt would conform to the hull of a flat-bottomed boat. This problem however, is a design problem and not an economic one. Since this thesis is intended to consider problems of economics rather than of design, some consideration will be given to the economic feasibility of such a double-belt system.

## Construction of Additional Locks

The last category of possible measures to alleviate congestion that we shall consider will be the construction of new additional locks. This solution is the one that instinctively comes to mind when one considers the problem of how to reduce congestion at the locks. Obviously, building another lock increases our capacity to move vessels past the lock complex. Our reasoning has already indicated however, that sheer increase in capacity to handle vessels does not necessarily confer any benefit upon the public. It is difficult to justify any expenditure of public funds

unless some benefit accrues to someone. In order for such a benefit to accrue there must be some increase in the convenience to lock users. The obvious benefit is reduction in travel time to those transiting the locks. Implicit in our previous discussion of the effect of increasing the length of the already existing locks was the suggestion that the more vessels that are locked through simultaneously, the greater the boat handling and administrative time involved and the greater the transit time. This would mean that in order to achieve savings in travel time, lock groups should be kept small. This would suggest that the most beneficial sort of a facility would be another lock of the same size or even smaller than the present small lock.

We now have a number of conflicting criteria bearing on the problem. We have seen (Figure 6) that we may expect upwards of 57,000 pleasure craft to arrive at the locks in 1970, and this is a relatively short range projection. A new facility must be capable of handling the traffic load of this period as well as being able to perform a useful function under the traffic loads of 10 to 20 years hence. This would tend to influence us toward selecting a larger lock chamber in our proposed facility. Simultaneously however, we must not forget the problem of water usage. Will enough water be available from the Lake Washington water shed to handle this traffic load? A larger lock chamber, even at shallow draft, tends to use excessive water, particularly during those lockages in which relatively few craft are passed through.

This problem of selecting the correct size for an additional facility will be considered in detail in this thesis, and the selected type of

new facility analyzed for its economic feasibility in conjunction with the other types of congestion reducing proposals under consideration.

# CHAPTER IV

## THEORY AND METHOD OF ATTACK

### The Economics of Public Finance

It is a generally accepted dictum of public finance that the benefits accruing to the public as a result of expenditures of public funds must be greater than the amount of those funds expended. This principle is basic and has received almost universal acceptance. Perhaps the best known and most universally used technique for comparing the benefits accruing to a project with the costs incurred by it, particularly in the economics of transportation, is the benefit/cost ratio, and it is this technique that will be used in the economic analyses of this report.

### Benefit/Cost Ratio

In its simplest form, the benefit/cost ratio may be stated as follows:

$$\text{(1)} \qquad \text{Benefit/Cost Ratio} = B/C$$

This relationship is equally true no matter whether benefits and costs are calculated as total accrued and incurred benefits and costs over the entire service life, benefits and costs per annum at any point during the service life, or as the present values of benefits and costs to be accrued and incurred in the future. That is to say, that when done properly, precisely the same numerical results are obtained no matter whether the calculations are carried out upon an anticipatory end of service life or annual basis.

Since the calculations tend in general to be somewhat simpler, the benefit-cost ratio will be calculated on an annual basis herein.

In a somewhat simplified form, the cost of building and operating a public facility might be expressed as:

$$C = PR + M + O \tag{2}$$

where:

C = annual operating cost

P = invested capital

R = capital recovery factor

M = annual maintenance cost

O = annual operating expenses

that is, the annual cost of operation is equal to the cost of amortizing the investment plus the cost of maintaining the facility (repairs, preservation, etc.), plus the annual operating charges (labor, costs, fuel, etc.). The composite equation, restated is:

$$B/C = \frac{B}{PR + M + O} \tag{3}$$

This statement of the benefit/cost ratio, while quite reasonable and simple, is not usable in this thesis for a number of reasons. The most serious of these is that the author does not feel competent to estimate the cost of any of the proposed facilities. In addition, there is very little way of knowing, except within rather wide limits of error, what the cost of maintaining and operating one of these facilities would be. Various simplifying assumptions must therefore be made. The first of these will deal with maintenance and operating costs.

It is reasonable to assume that the annual cost of maintaining and operating a facility should not exceed some reasonable percentage of the invested capital. Another way of stating this is that if a facility has a relatively short service life, the annual cost of amortization may be quite high in comparison to maintenance and operating costs; whereas a facility having lengthy service life may have maintenance and operating costs considerably in excess of the annual cost of amortizing the original investment. In both cases however, the maintenance and operating costs could be thought of as being some percentage of the original investment. If this percentage were assumed to be more or less constant, the benefit/cost ratio could be restated as follows:

$$B/C = \frac{B}{PR + kP} \qquad (4)$$

$$B/C = \frac{B}{P\,(R + k)} \qquad (5)$$

where:

k = maintenance factor

One consideration favoring the rationality of such a simplification is that various types of facilities obviously differ one from the other in their maintenance requirements. Such a differentiation can be accounted for by assigning various values to the maintenance factor k. This procedure will in fact be adopted herein. Obviously, those proposed facilities such as marine railways and beltways, having numerous moving parts exposed to the action of salt water, might be supposed to have a greater relative maintenance requirement than a masonry structure such as an additional lock. The various values of k that will be employed in this report are tabulated for convenient reference in Table 7 along with other appropriate economic constants.

Even the above simplification does not eliminate the problem of our inability to estimate the principal that must be invested in order to construct one or more of the proposed facilities. We do know however, that if a facility is to be marginally useful, that is if the benefits accruing are only exactly as great as the cost incurred, the benefit/cost ratio will be exactly equal to one. Rewriting our expression for benefit/cost ratio with the included additional criterion that the facility must be at least marginally useful:

(6) $$1 = \frac{B}{J\ (R + k)}$$

$$J = \frac{B}{R+k}$$

$$J = (1/R+k)\ B$$

(7) $$K = 1/R + k$$

(8) $$J = KB$$

where:

$J$ = justifiable cost

In this series of equations, the symbol J has been substituted for the symbol P. The thought behind this is that in previous expressions, P represented the actual cost of an actual facility. In equation 6 and subsequent expressions, the symbol J is used to symbolize a "justifiable cost," which may be either more or less than the actual cost, but is the maximum cost at which the facility would be economically justifiable, that is, marginally profitable. The criterion for actually constructing such a facility then would be:

(9) $$J \overline{>} P$$

## TABLE 7

## ECONOMIC CONSTANTS AND FACTORS

| Facility<br>Factor | Marine<br>Railway | Marine<br>Beltway | Additional<br>Lock(s) |
|---|---|---|---|
| k | 0.15 | 0.20 | 0.10 |
| | 5% | 5% | 5% |
| n | 25 | 25 | 50 |
| R | 0.0710 | 0.0710 | 0.0548 |
| R+k | 0.2210 | 0.2710 | 0.1548 |
| K = 1/R+k | 4.525 | 3.690 | 6.460 |

The facility should be built whenever the justifiable cost of the facility is equal to or greater than the actual cost of building the facility granted that no more advantageous use of available funds exists. In addition it will be noted that in equation 7 the quantity K is defined as the reciprocal of the sum of the capital recovery factor and the maintenance factor. This factor K is of course dependent on the interest rate and service life associated with the facility as well as upon the relative rate at which the facility will require maintenance, and will be unique for each installation.

## Interest Rate and Service Life

At this stage in our reasoning we are brought to a direct confrontation with the problems of interest rate and length of service life. There is a general, although not by any means universal, agreement among authorities in the field of public finance that interest must be considered to be charged on funds obligated to public works. As to what rate of interest should be charged there is no agreement whatsoever. Arguments have been advanced in favor of using interest rates as high as 15 or 20 percent. A very strong case can be made for the use of interest rates between 5 and 10 percent. On the otherhand, it is an obvious fact that governmental agencies are actually paying interest rates varying between 2 and 5 percent on monies they have borrowed. In this thesis an interest rate of 5 percent will be charged on assumed investments. This is reasonably liberal, that is to say it favors expenditures of funds to a greater degree than would some higher rate. At the same time it is certainly a more realistic figure

than some minimal rate such as the 2 to 5 percent charged on government bonds, and much better than charging no interest whatsoever.

Just as the selection of interest rate was based on judgment, so too must a judgment be made of the service life we may expect from the various proposed facilities. The necessity for this is obvious. When the cost of a facility must be recovered over a relatively short period of time, the annual cost of the facility may be quite high in proportion, even though the total invested capital may not be as much as that required for some other facility having a longer life expectancy. In making this judgment of service life we select either the physical service life of the facility, or its life of economic utility, whichever is the shorter. It is ridiculous to assign a service life of 50 years to a facility which will be economically obsolete within 20 and conversely one may not justify a service life of 50 years on the basis of continuing economic utility when in fact, the facility will physically disintegrate before this term is fulfilled.

In the specific instances at hand, we have several facts to guide our judgment. The first of these is the demonstrated fact that the present installation at the Hiram M. Chittenden Locks has already had a physical and economical useful life of nearly 50 years. Quite obviously an additional lock would have a physically useful life at least this long. Unfortunately we are not so sure that the economically useful life of an additional lock would be this great. Based entirely on the fact that pleasure boating is on the increase, the author feels that using a figure of 50 years for the service life of an additional lock is within the bounds of rationality.

All of the other proposed methods of reducing congestion at the locks which are under analysis here, are of a type which we instinctively feel will have a considerably shorter service life than a masonry structure. Marine railways and beltways, have numerous mechanical and metallic parts, and in the case of the beltways, the belting itself is a rapidly deteriorating material. Since all of these parts and materials will be continually subjected to severe use, weathering and the corrosive action of saltwater, the author feels that a practical physical service life of no greater than 50 percent of that assigned to the masonry structure may be expected of these types of installations. In consequence of this, a service life of 25 years will be used for all facilities other than the proposed additional lock.

It would be well to mention here that in making these estimates of interest rate and service life, the author is taking no undue liberty. In all varieties of economic analyses, with the exception of a very few limited cases (such as facilities built with the proceeds of a bond issue, and facilities of a type having a well-established service life), these values are based on judgments made by the analyst.

Now that an interest rate and service lives have been settled upon, the capital recovery factor R may be taken from any standard table of economic series. Values of the capital recovery factor that will be associated with the various facilities under consideration are shown in Table 6. Also in this table is shown the summation of the capital recovery factor and the maintenance factor for each facility and the calculation of K, the constant defined by equation 7 and appearing in equation 8.

## Determination of Benefits

So far in the development of our approach to benefit/cost analysis we have not touched upon the question of calculating the benefits that may be expected to accrue through the installation of some new facility. One approach to the calculation of these benefits commonly used in benefit/cost studies of land transportation facilities is :

$$B = W\Delta t + \Delta H \qquad (10)$$

where:

$W$ = willingness to pay for time savings

$\Delta t$ = time saved

$\Delta H$ = saving in operating costs

The benefits here are considered to be compounded from those benefits that accrue due to savings in the time necessary to travel from an origin to a destination, and those benefits that accrue due to a lessening of the actual cost of operating vehicles on that facility. Since the quantity of time savings is usually easily calculated, the total time savings are expressed as the quantity of time saved multiplied by a factor sometimes called the "willingness to pay." This "willingness to pay" is the worth of the public's time exclusive of any consideration of the vehicular operating costs. Another and perhaps better way of putting this is to say that this is the amount of money that the rational economic man should be willing to pay for an hour's saving in travel time. The term representing saving in operating costs that appears in equation 10 is usually assumed to be

principally dependent upon the distance that is saved by installing a new facility. In actual practice, benefits counted under this term are usually fuel savings. The author feels that such a statement, while admirable for its simplicity, does not reflect completely the true state of affairs. The cost of operating a vehicle is not due to fuel costs alone but is a combination of fuel costs, lubricant, general repair, spare parts, depreciation on original investment, insurance costs, and miscellaneous expenses. Of these, very obviously fuel and lubricant consumption depend on the distance traveled. Depreciation, insurance, general repair and spare parts also should, in general, tend to be some function of distances traveled. Since the actual savings in distance traveled are a function of the time savings, given some average velocity, all quantities involved in expressing benefits must be some function of the travel time involved. This general concept is expressed by equation 11.

$$B = W \quad t + \Delta t \cdot f\,(\Delta M, \Delta F, \Delta D, \Delta I, S, \Delta L) \tag{11}$$

where:

$\Delta M$ = savings in maintenance costs

$\Delta F$ = fuel and lubricant savings

$\Delta D$ = savings in depreciation

$\Delta I$ = savings in insurance costs

$S$ = average speed of travel

$\Delta L$ = savings in distance

then:

$$B = \Delta t \cdot f\,(W, \; M, \; F, \; D, \; I, S, \; L) \tag{12}$$

If we accept this then we must accept the fact that the benefits may be expressed as the savings in travel time multiplied by some function of the willingness to pay for time savings, savings in maintenance costs, fuel savings, savings in depreciation, insurance, average speed and savings in distance traveled as shown by equation 12. This rather complex function must then equal the cumulative value of time savings to the public, including all considerations of the worth of time itself as well as vehicular operating costs, etc.

(13) $V = f\ (W, M, F, D, I, S, L)$

where:

$V$ = the value of time

then:

(14) $B = V \Delta t$

and:

(15) $J = KV\Delta t$

This leads to the conclusion, expressed by equation 14, that all benefits accruing to the new facility may be expressed as the quantity of time savings multiplied by the value of time to the public. When this expression for benefits is substituted into equation 8, the expression shown as equation 15 results. In this equation the justifiable costs of a new facility is equated to the product of the time saving realized through the facility, the value of time to the users of the facility, and a factor dependent upon interest rate, service life, and relative maintenance costs. This is the

final form that the expression of benefit/cost analysis shall take in this thesis.

Values of the factor K are already available in Table 6. The remaining tasks of this thesis, as far as evaluating the economic feasibility of the proposed improvements at the Hiram M. Chittenden Locks, are to establish the numerical values of the two factors V and t.

## Method of Attack on the Value of Time

What is the value of leisure time? Very often when a man engaged in some leisure time activity is asked this question, he will blithely reply "nothing." Is this true? Is leisure time worthless? If so, we should be willing to give up our leisure time, devoting these worthless hours to more productive pursuits. Yet how many people would be willing to give up these hours that they consider to be worthless?

Even during the productive hours of the day, the value of time is difficult to establish. The fact that a man is paid a set hourly wage does not mean that his time is worth precisely that. A man must return to his employer some additional value over and above his wage if he wishes to remain in that employ. We might then say that the man's time is worth his wage plus the profit he produces for his employer during the period of that wage. Under any circumstances we have established this value by use of the "marketplace" technique, that is using the actual monetary sale price of laboring time in the open employment market.

It would be difficult to apply this method to leisure time. There would certainly seem to be no way of attaching a dollar and cent value to time spent in complete idleness. This problem, while perhaps insoluble,

is at least not unapproachable. When men pay large sums of money to purchase elaborate equipment to assist them in the enjoyment of a relatively few hours of leisure time, the mind instinctively leaps to the conclusion that these men must consider their leisure time to be quite valuable.

Fortunately perhaps for the purposes of this investigation, the value of leisure time to those who choose to spend this time engaged in yachting and water sports is bounded by a few definite parameters. These people spend some definite amount of money on the goods and services that enable them to enjoy these pursuits, and they spend some definite number of hours actually engaged in enjoying the fruits of these expenditures. We are immediately led to the conclusion that if for any particular yachtsman, we divide his total expenditure for boating goods and services by the total annual time he spends engaged in boating activities, we would have for that particular individual an index representative of the value he places on his leisure time. If this were done repetitively for a sample large enough or of such a composition to be representative of the general boat population, we could develop a figure indicative of the value of time to the average boating enthusiast.

Let us now consider the case of a yachtsman who, having expended a considerable amount of money to purchase a boat, accessories, fuel, moorage, etc., is denied the use of this investment for some reason or other. Let us for instance consider the case of the yachtsman, moored in Portage Bay, who wishes to spend a Sunday afternoon cruising Puget Sound. If there were no other boats waiting at the locks, he might reasonably expect to be passed out through the small lock in from 5 to 10 minutes. When he returns that

night, if there were no other traffic present, he might expect another quick trip through the locks back to his moorage. For a four or five hour cruise on Puget Sound, he might then expect to spend 15 or 20 minutes, 5% or 6% of the total time involved, in passing to and from through the locks. (There is no need to consider the time involved in transiting the ship canal since he would have to travel this distance even if the lakes and Puget Sound were at the same level and no locks in between). Let us then turn from this idyllic picture to the actual situation. Because of the heavy concentrations of traffic at the locks on Sunday afternoons and evenings, our yachtsman will most probably be forced to use the larger lock, spending perhaps an hour and a half traveling either way. Our yachtsman is now spending as much as 40% of his time transiting the locks. Instead of 15 or 20 minutes being taken up by these passages he must spend 3 hours there. This is an increase of over 2½ hours.

Now consider the motivation which originally prompted this yachtsman to seek passage through the locks to Puget Sound. Was he principally interested in the placid pleasures of salt-water cruising, or did he wish to pass through the locks because he likes to pass through locks? It is very doubtful indeed if our yachtsman seeks to pass through the locks simply to experience maneuvering the craft to keep from being jostled, bumped, or even rammed by some 50 other boatmen. For most purposes, the time that a yachtsman spends at the locks are a total loss. Every minute there is a minute in which he is unable to enjoy the recreation he is really seeking. Excessive delays in passing through the locks represent a distinct disservice to the yachtsman. Since we can easily demonstrate that the average

yachtsman spends some given amount of money per hour in pursuit of his sport, it would certainly seem reasonable to assume that when he is delayed an hour in passing through the locks, the disservice he is thus occasioned is at least equivalent to this amount.

Since the method of quantifying the value of time used herein, and consequently the accuracy of any numerical results produced, is dependent upon this argument, it would perhaps be well to state it more formally. Such a statement is as follows:

$$V_i = E_i / T_i \qquad (16)$$

where:

$V_i$ = the value of time to some individual yachtsman

$E_i$ = expense of owning and operating his specific vessel

$T_i$ = time spent in using that vessel

This equation states that the value of time will be considered as approximately equal to the total expense of owning and operating a craft divided by the number of hours spent using that craft. Note that we say that the value of time is only approximately equal to this function. Referring back to the derivation of equation 14 it may be seen that the value of time is, as defined herein, a function of the willingness to pay for time savings as well as being a function of those factors which contribute to the expense of ownership and operation. Obviously no consideration is given to the willingness to pay for time savings in equation 16, and for this reason the value of time can be only considered to be approximated by the procedure of dividing expense by usage time.

Statistical Methodology

Thus far in our development of a methodology for quantifying the value of time, we have settled upon an expression (equation 16) which will permit us to calculate, at least approximately, the value of time to an individual yachtsman. We have also mentioned that if calculations of this sort were carried out for a large enough sample of pleasure craft to be representative of the general boat population, then it would be possible to develop by some statistical method a measure of the value of time representative of the general population of pleasure craft in Seattle. It is therefore appropriate for us to now give some consideration to statistical methodology and to what statistical measure will be used to indicate the value of time to the general boat population.

The idea of using an average or mean value immediately leaps to mind. This is in fact what we will do but we will use a weighted average rather than a simple one.

Consider the case of two boat owners. Both of them spend identical amounts each year to own and operate their craft, but the first one (owner A we shall call him) operates his vessel one thousand hours a year in comparison to owner B who operates his only one hour each year. Two facts are immediately obvious. First of all owner B must be assigned a value of time a thousand times as great as that which will be assigned to owner A in accordance with the expression we have developed to express this value of time. Secondly, we see that owner B contributes to the general traffic pattern only one one-thousandth of the amount contributed by owner A. If we were to take a simple arithmetic mean of the value of time to these two owners, the figure thus obtained would be heavily influenced by the excessive

value of time to owner B who contributes only negligibly to the traffic problem, and who by inference will receive only negligible benefits from the installation of any facility to relieve traffic congestion. To obviate such an anomolous situation and to insure that the figure developed for the value of time is truly representative of this value to the user, the contribution to the congestion problem. This could be done by multiplying the value of time for each vessel investigated, as calculated by equation 16, by the amount of time that each owner spends using that vessel. These individually weighted values of time could then be summed up and divided by the sum of all usage times reported, thus producing an appropriately weighted figure for the value of time to the general boat population. The mathematics of doing this are as follows:

$$V = \frac{\sum_1^n V_i T_i}{\sum_1^n T_i} \tag{17}$$

where:

V = weighted mean value of time to the general boat population

but: $V_i = E_i / T_i$

then:

$$V = \frac{\sum_1^n \frac{E_i T_i}{\cancel{T_i}}}{\sum_1^n T_i}$$

$$V = \frac{\sum_1^n E_i}{\sum_1^n T_i} \tag{18}$$

From these manipulations we may see that it will never actually be necessary to calculate, by means of equation 16, the value of time to any individual yachtsman. Instead we merely need to sum up all ownership and operational costs for the vessels under consideration and then divide them by the total

ssage time for the same vessels, the result of this operation being a figure appropriately weighted for each vessel's contribution to the traffic problem and representative of the mean value of time to the general boat population.

## Method of Attack on Savings in Travel Time

In equation 15 the justifiable cost of investment in a facility was held to be equal to the product of a constant multiplied by the value of time and then multiplied again by the savings in travel time thus achieved. Appropriate values of the requisite constant have been calculated and are available already, and we have established a methodology for quantifying the value of time. The only task yet remaining in our consideration of theory necessary to this investigation is the development of a procedure for establishing the magnitude of the time savings that would be occasioned by the installation of a new facility.

The keys to developing such a procedure lie first of all in the nature of the quantity we are seeking to establish, and secondly in the overall traffic pattern and pattern of operation of the locks. The quantity we are trying to establish is the amount of time that would be saved by installation of a new facility. The operative word here is "saved." It would be conceivably possible for us to calculate the total travel time involved for all vessels passing through the locks in some given period of time and then recalculate the total travel time that would be occasioned by the passage of the same number of vessels during the same period of time through the locks with the additional facility in place. The difference in these two quantities would then be the saving in travel time achieved

by the installation of the new facility. The mathematical expression of this procedure would be:

$$\Delta t = T_p - T_f \tag{19}$$

where:

$T_p$ = total travel time through present facility

$T_f$ = total travel time through expanded facility

There would clearly be little attraction to such a procedure if the saving in travel time were calculable directly.

In Chapter [illegible], when operations at the locks were being discussed, it was mentioned that great concentrations of traffic tend to occur in the late morning, afternoons and early evenings of weekends and holidays and that to accomodate these peaks in traffic, the large lock is pressed into service when the rate of arrivals exceeds the traffic handling capacity of the small lock. This pattern of events provides the second key to our development of methodology for the quantification of savings in travel time. Even the most casual observation of the records kept at Hiram M. Chittenden Locks shows immediately that there are very few vessels (and virtually no pleasure craft) passing through the locks between the hours of midnight and eight o'clock in the morning. The present installation is perfectly adequate to handle such off-peak traffic. Traffic passing through an expanded facility during the same off-peak hours could achieve absolutely no saving in travel time. In fact, the present facility is adequate to handle all traffic loads except those which occur during the weekend and holiday peaks. During off-peak hours there would be no necessity for any traffic to use the new additional facility.

We will now consider the effect of the new facility during a period of peak traffic flow. Where would the vessels come from that use the additional facility? Would they be vessels that would otherwise have used the small lock or which would otherwise have used the larger lock available under the present arrangement? Considering the fact that transit time for the large lock is about three times that of the small lock under peak traffic loads, it becomes obvious that the vessels passing through the new facility would be those which would otherwise be forced to pass through the large lock with its accompanying lengthy time of passage. It may be seen then that the principal effect of an additional facility at the locks would be to drain off traffic from the large locks during the periods of peak operation. This simplifies our approach to the calculation of savings in travel time considerably. Instead of having to calculate the total time of transit experienced by every vessel passing through every portion both of the present lock facilities and the expanded lock facilities and then to determine the difference between the two, we now need to consider only those vessels which are directly benefited by the additional capacity to move traffic.

When equation [illegible] is revised to incorporate this concept, the result is:

$$\Delta t = N(t_1 - t_n) \qquad (20)$$

$N$ = number of vessels diverted from large lock to new facility

$t_1$ = time required for a transit via the large lock

$t_f$ = time required for a transit via the new facility

This equation states that the saving in travel time may be calculated by multiplying the difference between the time required for a single transit of the large lock and that required for a single transit of the additional facility by the number of vessels diverted from the large lock to the new facility. Since all the quantities involved in this expression are reasonably elementary, this approach is clearly simpler than an attack based on travel times for all vessels passing the present and expanded facilities, and is the method of attack that will be used herein.

Required Data

Now that we have completed our development of our theory and method of attack to be employed in the numerical analyses incident to this thesis, it would seem well to summarize this method of attack and to list the types of data that must be collected and evaluated in order to pursue our selected approach. In the process of developing equation 15, since making estimates of the cost of improvements at the locks was beyond the author's capability, it was concluded that any facility which would be at least marginally **profitable would be considered justified and that the numerical analyses herein** would be directed to the determination of the capital investment that might properly be incurred in the installation of such a marginally profitable facility. Having defined this capital outlay for a marginally profitable facility as the justifiable cost, it was determined that this justifiable cost would be equal to the product of a constant dependent upon service life,

interest rates and relative maintenance requirements of various types of facilities; the value of time to those who would benefit from the new facility; and the amount of time saved as a result of the new installation. Having made necessary decisions concerning its parameters, the constant K was calculated for the various types of facilities under consideration and tabulated in Table 7. The individual value of time V, was then shown to be approximately equal to the expense of owning and operating a vessel divided with the time actually spent using that vessel and the appropriate statistical measure of the value of time to the general boat population was found to be calculable simply by dividing the sum of all ownership and operational costs by the sum of all usage times. Finally the time savings incident to a new installation were shown to be dependent upon the number of vessels diverted from the present large lock to the new facility and upon the difference between the time required for a single transit through the new installation as compared to the present large lock.

The quantification of the value of time will be pursued by means of a survey of boat owners in the Seattle area. These owners will be questioned concerning amounts they spend to purchase and operate their craft and the time they spend in that operation. Given a sufficient number of answers to the questions proposed in this survey to reflect adequately the composition of Seattle's boat population, it will be possible to determine the average cost of owning a boat and the average time spent using it. It will then be possible to calculate the average value of time by means of equation [illegible].

In order to quantify the time savings that will be occasioned by the installation of a new facility, two things will have to be done.

First, records at the Hiram M. Chittenden Locks will have to be examined in order to determine the length of time required for a passage through the large locks and the number of vessels that would be diverted from these locks to a new facility each year. Secondly, it will be necessary to either calculate or estimate the transit time over each of the proposed additional facilities. Given these entering arguments, it will be possible to calculate total annual time savings by means of equation 2[illegible]. These figures may then be re-substituted in equation 15, giving the justifiable cost of the proposed facility during the time period under consideration.

## CHAPTER V

## QUANTIFICATION OF THE VALUE OF TIME

### Data Collection Procedures

Very early in the course of the investigation which forms the subject of this report, it became apparent that whatever mathematical approach was eventually to be used, some monetary value would have to be placed upon the leisure hours spent in the enjoyment of boating. The development of a theoretical basis for such a quantification, and a methodology for actually executing it, were two of the first tasks undertaken. This theory, already presented in the preceding chapter, indicated that it would be necessary to determine how much various yachtsmen spent in order to own, operate and maintain their craft, and how many hours per year they spend enjoying these investments. Figure 9A is a reproduction of the questionnaire used for this purpose.

### Evaluation of Questions and Answers

Figure 9B contains a summary of the author's evaluation of the adequacy both of the questionnaire used in conducting the survey incident to this investigation and of the answers received from this survey as well as the usefulness of these answers. Of the [illegible] subquestions asked, [illegible] are evaluated as useless, unnecessary, or redundant. An additional [illegible] subquestions are evaluated as being of no use to this study. This means that half of the questions asked in this survey were absolutely meaningless as far as the intent of this investigation was concerned.

## LAKE WASHINGTON SHIP CANAL CONGESTION STUDY

Are you interested in relieving congested conditions in the Lake Washington Ship Canal? In eliminating delays in passing through H. M. Chittenden Locks?

These problems are currently being studied by D. W. Harned, candidate for Master's degree at the University of Washington. The paper that will result from this study will contain an evaluation of various methods of alleviating these problems plus some uniquely new proposals.

This paper may well be the only publication available to public and private groups interested in the yachtsman's problems during the next several years.

Help solve these problems! Fill out this questionnaire and return it to your yacht club or marina!

Questions 4, 5, 6 and 7 are of extreme importance and should be filled out with reference to vouchers and receipts wherever possible and to the very best of your knowledge elsewhere.

1. Type of craft: (give brief description of hull types, sail rig, type and number of motors or engines, etc.) ____

2. Dimensions:
   a. Overall length including all projections & overhangs in feet & in. ____
   b. Overall width including all projections & overhangs in ft. & in. ____
   c. Overall height from waterline to highest projections in ft. & in. ____

3. Moorage data:
   a. Do you moor your craft in the water
      i. All year ____
      ii. all summer with winter storage on land ____
      iii. seldom, launch and retrieve each trip ____
   b. Name of body of water where moorage facility is located ____
   c. Name of moorage facility ____
   d. Which launching ramp do you use? ____
   e. Rate you are charged for moorage:
      i. per foot ____
      ii. are these per month, week, day or what? ____
      iii. Total ____
   f. Is your moorage covered? ____

4. Date boat was purchased ____ new or used ____
   How old if used ____

5. Cost of boat:
   a. Total original cost including all taxes, registration fees, value of trade-in, etc. ____
   b. Estimate of present net resale value of boat (amount of money you would receive) ____

6. Maintenance costs:
   a. Estimate of total amount of money spent during the past twelve months for:
      i. moorage ____
      ii. maintenance & repair ____
      iii. fuel ____
      iv. out of water storage ____
      v. taxes and fees ____
      vi. launching & retrieval ____

FIGURE 9 A

   b. Estimate of total amount of money spent all during time you have owned this craft for:
      i. moorage ____
      ii. fuel ____
      iii. maintenance & repair ____
      iv. out of water storage ____
      v. taxes & fees ____
      vi. launching & retrieval ____

7. Usage time:
   a. Estimate of total number of hours you have spent underway on this craft in the past twelve months: ____
   b. Estimate of total number of hours spent underway on this craft during all the time you have owned it: ____

8. Bridge opening data:
   a. Does your craft require any bridge to be opened for its passage? ____
   b. Which ones? ____
   c. Number of times each of these has been opened for you during the past twelve months? ____ since you have owned the craft? ____

9. Lockage data:
   a. Estimate of % of underway time spent seaward of Ballard locks ____
   b. Estimate of additional % of underway time spent in transit to and from between the locks and your moorage ____
   c. Is the center of your boating interest to seaward of the locks? ____
      in Lake Washington? ____ Elsewhere? ____ Where? ____
      What is this interest? ____
   d. Estimate of average number of vessels inside the locks during a transit based on your experience ____
   e. Maximum number you have seen inside the locks during a transit ____
   f. In you opinion are the locks being used to maximum capacity in times of heavy traffic? ____
   g. Estimate of maximum number of vessels you have ever seen waiting to transit:
      i. out through the locks ____
      ii. in through the locks ____

10. Delays:
   a. Estimate of total number of minutes delayed while waiting for bridge openings during last twelve months. ____
   b. Estimate of total number of minutes delayed while waiting in line at the locks during last twelve months. (not including time actually spent being raised or lowered).
      i. going out ____
      ii. coming in ____
   c. Maximum number of minutes of delay you have ever experienced at the locks (not counting time spent being raised or lowered).
      i. going out ____
      ii. coming in ____

11. Are you considering moving to salt-water moorage? ____ Why? ____

12. What factors would influence you to move to salt-water moorage? ____

13. Do you prefer covered to uncovered moorage? ____ Why? ____

14. Other remarks? ____

FIGURE

# EVALUATION OF QUESTIONS & ANSWERS - LAKE WASHINGTON SHIP CANAL CONGESTION SURVEY

| Question # | Subject of Question | Evaluation of Question | Evaluation of Answers | Evaluation of Usefulness in this Study | Suggested Improvements |
|---|---|---|---|---|---|
| 1 | type vessel | not specific enough | barely satisfactory | statistical adjustments | List hull, rig & engine types with boxes for number & horsepower of engines to be filled in. Ask rate of fuel usage in gals. per hour. |
| 2 | Dimensions | satisfactory | excellent | statistical adjustment | Use tabular rather than literal format. |
| 3a | moorage period | satisfactory | excellent | General interest | Use tabular format. |
| 3bcd | moorage location | not extensive enough | satisfactory | none | Also ask residence location; distance & travel time to moorage. |
| 3e | moorage rate | satisfactory | satisfactory | none | All rates monthly-eliminate **3e.iii.** - use tabular format. Also ask for insurance rate charged and cost of fuel per gallon. |
| 3f | covered moorage | redundant | satisfactory | none | Combine with question 13. |
| 4 | purchase date | satisfactory | excellent | none | Use tabular format-combine with 5. |
| 5a | Orig. cost | barely satisf. | barely satisf. | annual ownership cost | subdivided into parts, tabular format. |
| 5b | **resale value** | **not extensive enough** | satisfactory | insurance cost | Also ask value of any major capital improvements, how financed, interest rate on financing & maximum interest rate on other investments. |
| 6a | Annual maintenance costs | incomplete | satisfactory | operational costs | Ask for insurance costs - cross check with data on insurance rates, moorage rates, fuel usage & cost and hours of operation |
| 6b | total maintenance costs | useless | useless | none | Replace with question on major capital improvements mentioned in connection with question 5b. |
| 7a | annual usage | satisfactory | approximate | value of time | Also ask for engine-hour meter readings; cross check with fuel usage data. |
| 7b | total usage | useless | useless | none | Omit. |
| 8 | bridge openings | satisfactory | satisfactory | none | |
| 9a,b | % time at sea | useless | erratic | none | Omit-use question 9c for this purpose. |
| 9c | boating interest | satisfactory | satisfactory | general interest | Use tabular format. |
| 9defg | boats at gov't locks | unnecessary | useless | none | Better data available at H.M.C. Locks. |
| 10 | Delays | unnecessary | useless | none | This data requires observation & recording. |
| 11. | Salt water moorage | satisfactory | excellent | general interest | List factors causing move in tabular form for check-marking |
| 12. | Salt water moorage | satisfactory | excellent | general interest | Combine with 11, use tabular format. list factors for checking. |
| 13. | covered moorage | satisfactory | excellent | general interest | Combine with 3f., list factors for checking. |
| 14. | remarks | unnecessary | facetious | none | Omit. |

Other possibly desirable questions:

What maximum toll would you be willing to pay to pass through the locks?

What is your annual income?

Another substantial group of questions and subquestions were evaluated as being only of general interest. The results of these particular questions tended to substantiate subjective conclusions of the author on these particular points. The general conclusion to be drawn from this is that the questionnaire could have been halved or quartered in size, producing a much handier and cheaper form, without the loss of any significant data.

Figure 9E also tabulates a number of suggested possible improvements in the questionnaire. The concensus of these is that a tabular rather than a literal format should have been used in asking the questions and the desirable answers should have been listed for checking. Such a procedure would make data reduction from this form considerably quicker and would probably tend to increase the reliability of the answers obtained. One or two extremely desirable questions were omitted, such as cost of insurance on craft surveyed. In addition, there are a number of additional questions and subquestions that might be inserted in a study of this type which would enable certain additional statistics to be developed if such were desired and would permit cross-checking of some of the values of ownership costs and of usage time.

Tables 8, 9, 10 and 11 contain tabulations of the actual results of the survey for those questions which proved to be reasonably successful. Table 12 is a summary of the result of those questions not concerned with the calculation of the value of time. These results illustrate the general terdency to spend considerable portions of time to seaward of the Hiram M. Chittenden **Locks** the general preference for fresh water moorage in salt-water areas, overwhelming preference among inboard motor craft owners for

## TABLE [illegible]

## TABULATION OF RESULTS

## LAKE WASHINGTON SHIP CANAL CONGESTION SURVEY - OUTBOARD RUNABOUTS

| | Length ft. | Period[1] in water | Annual[2] ownership cost $ | Usage Hours | % time at sea | % time locks to moorage | salt[1] water moorage | covered[1] moorage |
|---|---|---|---|---|---|---|---|---|
| | 16.0 | 1 | 261.5 | 360 | 99 | 0 | 5 | 11 |
| | 19.0 | 2 | 957.00 | 100 | 50 | 8 | 6,8 | 9 |
| | 18.0 | 22 | 711.00 | 100 | 1 | 2 | 6,7 | 9 |
| | 16.0 | 2 | 210.00 | 130 | 2 | 6 | 6,8 | 9 |
| | 20.0 | 1 | 486.00 | 72 | 0 | 0 | 6,8 | 9 |
| Total(5) | 89.0 | 1-2<br>2-3 | 2625.50 | 762 | 152 | 16 | 1-5 4-6<br>1-7 3-8 | 4-9<br>1-11 |
| Average | 17.8 | -- | 525.10 | 152.4 | 30.4 | 3.2 | -- | -- |

Notes:

1. CODE — INTERPRETATION

| CODE | INTERPRETATION |
|---|---|
| 1 | Moored in water year round |
| 2 | Stored on land in winter |
| 3 | Stored on trailer, launch and retrieve |
| 4 | Presently considering moving to salt-water moorage |
| 5 | Already moored in salt-water |
| 6 | Not considering moving to salt-water |
| 7 | Might consider moving to salt-water |
| 8 | Would never consider moving to salt-water |
| 9 | Prefer covered moorage |
| 10 | Prefer open moorage |
| 11 | Not applicable to my boat |

2. Calculated value, see Table 13

## TABLE 9

## TABULATION OF RESULTS

## INBOARD MOTORBOATS

| | Length ft. | Period in water[1] | Annual ownership cost $[2] | Usage hours | % time at sea | % time locks to moorage | Salt water moorage | Covered moorage |
|---|---|---|---|---|---|---|---|---|
| | 41.0 | 1 | 3063. | 300 | 75 | 20 | [illegible] | [illegible] |
| | 43.0 | 1 | 3131. | 600 | 5 | 5 | [illegible] | [illegible] |
| | 35.0 | 1 | 5673. | 400 | [illegible] | 1 | [illegible] | [illegible] |
| | 38.0 | 1 | 6975 | 400 | 5 | 5 | 4 | [illegible] |
| | 30.0 | 1 | [illegible]73. | 100 | [illegible] | 5 | [illegible] | [illegible] |
| | 35.0 | 1 | 1643. | 200 | [illegible] | [illegible] | [illegible] | [illegible] |
| | 32.0 | 1 | 1585. | 100 | 75 | 15 | [illegible] | [illegible] |
| | 36.5 | 1 | 1734.4 | 380 | 95 | 2 | [illegible] | [illegible] |
| | 60.0 | 1 | 3[illegible]00. | 150 | 60 | 5 | [illegible] | [illegible] |
| | 53.0 | 1 | 4914. | 500 | [illegible] | 2 | [illegible] | [illegible] |
| | 34.0 | 1 | 3510. | 2[illegible]0 | [illegible] | 10 | [illegible] | [illegible] |
| | 36.0 | 1 | 3[illegible]2.4 | 200 | 75 | [illegible] | [illegible] | 10 |
| | 38.0 | 1 | 4316. | 250 | 7 | 3 | [illegible] | [illegible] |
| | 30.0 | 1 | 2480. | 200 | 75 | 2 | [illegible] | [illegible] |
| | 50.5 | 1 | 6116.3 | 275 | 95 | 5 | [illegible] | [illegible] |
| | 30.0 | 1 | 1444.5 | 200 | [illegible] | 10 | [illegible] | [illegible] |
| | 46.0 | 2 | 3310. | 150 | 99 | 1 | [illegible] | [illegible] |
| | 43.0 | 1 | 5374. | 250 | [illegible] | [illegible] | [illegible] | [illegible] |
| | 52.0 | 1 | [illegible]27[illegible]. | 235 | [illegible] | 5 | [illegible] | [illegible] |
| | 36.0 | 1 | 3918. | 40 | 75 | 10 | [illegible] | [illegible] |
| | 42.0 | 1 | 2490. | 110 | 95 | [illegible] | [illegible] | [illegible] |
| | 30.0 | 1 | 2436. | 170 | [illegible] | [illegible] | [illegible] | [illegible] |
| | 25.0 | 3 | 723. | [illegible]5 | 50 | 10 | [illegible] | [illegible] |
| | 36.5 | 1 | 3076.8 | 100 | 5 | 5 | [illegible] | [illegible] |
| Total (24) | 932.5 | 1-22, 2-1<br>3-1 | 84,993.4 | 5693 | 2047 | 140 | [illegible] | [illegible] |
| Average | 38.9 | -- | 3541.39 | 237.21 | 85.3 | [illegible] | -- | -- |

TABLE 10

TABULATION OF RESULTS

SMALL SAILBOATS

| | Length ft. | Period[1] in water | Annual[2] ownership cost | Usage hours | % time at sea | % time locks to moorage | Salt[1] water moorage | Covered[1] moorage |
|---|---|---|---|---|---|---|---|---|
| | 18.0 | 3 | 289.25 | 250 | 1 | .5 | 6,7 | 11 |
| | 21.25 | 1 | 656.00 | 150 | 100 | 0 | 5 | 11 |
| | 14.0 | 3 | 173.00 | 350 | 1 | 1.5 | 4 | 11 |
| | 14.0 | 3 | 286.00 | 300 | 0 | 0 | 6,7 | 11 |
| | 18.17 | 3 | 147.10 | 25 | 70 | 10 | 6,7 | 11 |
| | 19.0 | 3 | 245.60 | 100 | 0 | 0 | 6,7 | 11 |
| | 19.5 | 3 | 353.25 | 100 | 10% | 5% | 6,[illegible] | 11 |
| | 14.0 | 3 | 361.65 | 100 | 5% | 0 | 6,7 | [illegible] |
| | 19.0 | 3 | 368.73 | 200 | 20 | 7.5 | 6,7 | 11 |
| | 17.0 | 3 | 354.15 | 80 | 0 | 0 | 4 | 10 |
| Total (10) | 173.92 | 1-1<br>3-9 | 3234.72 | 1655 | 207 | 24.5 | 2-4, 1-5<br>7-[illegible], 4-7,<br>3-[illegible] | 1-[illegible], [illegible]-[illegible]<br>[illegible]-11 |
| Average | 17.4 | -- | 323.47 | 165.5 | 20.7 | 2.45 | -- | -- |

## TABLE 11

## TABULATION OF RESULTS

## LARGE SAILBOATS

| | Length ft. | Period[1] in water | Annual[2] ownership cost | Usage hours | % time at sea | % time locks to moorage | Salt[1] water moorage | Covered[1] moorage |
|---|---|---|---|---|---|---|---|---|
| | 30.5 | 1 | 1605.00 | 300 | 75 | 7 | 4 | 11 |
| | 73.0 | 1 | 16802.00 | 400 | 0 | 0 | 6,[illegible] | 11 |
| | 25.0 | 1 | 948.00 | 300 | 0 | 17 | 6,[illegible] | 11 |
| | 50.0 | 1 | 2911.00 | 271 | 0 | 0 | 5 | [illegible] |
| | 25.5 | 1 | 1553.00 | 800 | [illegible] | 0 | 5 | 11 |
| | 25.92 | 1 | [illegible]57.00 | 300 | [illegible]0 | 0 | 5 | 11 |
| | 36.0 | 1 | 1166,63 | 400 | 50 | 40 | 6,[illegible] | 11 |
| | 29.17 | 1 | 978.00 | 210 | 40 | [illegible] | 6,7 | 11 |
| | 23.17 | 2 | 1301.20 | 165 | 50 | 10 | 6,8 | 11 |
| | 30.0 | 1 | 2059.00 | 500 | [illegible] | 2 | 5 | 11 |
| | 23.0 | 1 | 744.40 | 225 | 35 | 3 | 4 | [illegible] |
| | 29.0 | 1 | 576.00 | 150 | 60 | [illegible] | 6,7 | [illegible] |
| | 26.0 | 1 | 1113.50 | 100 | 10 | 1 | 6,7 | 11 |
| | 26.0 | 1 | 5[illegible]4.[illegible] | 200 | 20 | 4 | 4 | 11 |
| | 23.0 | 1 | 831.00 | 1[illegible]0 | [illegible] | 0 | 5 | 11 |
| | 50.0 | 1 | 1136.00 | 350 | 95 | 5 | 4 | 11 |
| | 45.0 | 1 | 2143.00 | 15 | [illegible]0 | 10 | 6,[illegible] | 11 |
| | 29.0 | 1 | 1150.00 | 240 | [illegible]5 | 2 | 6,7 | 11 |
| | 32.75 | 1 | 3813.16 | 200 | [illegible]5 | 10 | 6,8 | [illegible] |
| | 32.0 | 1 | 1181.00 | 100 | 100 | 0 | 5 | 11 |
| | 28.0 | 1 | 1849.00 | 220 | 60 | 20 | 4 | 11 |
| | 30.0 | 1 | 1801.80 | 775 | [illegible]5 | 0 | 5 | 11 |
| | 2[illegible].92 | 1 | 1001.50 | 600 | [illegible]9 | 0 | 5 | 11 |
| | 36.0 | 1 | [illegible]12.00 | 175 | 70 | 0 | 4 | 11 |
| | 26.0 | 1 | 429.00 | 226 | 30 | 12 | 6,7 | 11 |
| | 26.5 | 1 | 775.80 | 150 | 40 | 15 | 6,7 | 11 |
| | 36.0 | 1 | 1111.50 | 150 | 30 | 5 | [illegible] | 11 |
| | 26.5 | 2 | 935.[illegible]0 | 48 | 33 | 17 | 6,8 | 11 |
| | 36.0 | 1 | 515.00 | 150 | 70 | [illegible] | [illegible],7 | 11 |
| | 36.0 | 1 | 4712.00 | 300 | [illegible]5 | 5 | [illegible],7 | 11 |
| | 36.0 | 1 | 1639.00 | [illegible] | 30 | 15 | [illegible] | 11 |
| | 26.5 | 1 | 763.[illegible]0 | 500 | 40 | 5 | 6,7 | 11 |
| | 27.0 | 2 | 1[illegible]11.00 | 150 | 40 | [illegible] | [illegible] | 11 |
| | 29.17 | 1 | 751.00 | 3[illegible]7 | [illegible] | [illegible]4 | 6,7 | 11 |
| | 30.25 | 1 | 1460.00 | 200 | 75 | 15 | 4 | 11 |
| | 36.0 | 1 | 5[illegible]10.00 | 500 | [illegible] | [illegible] | [illegible] | 11 |
| | 3[illegible].0 | 1 | 2009.00 | 450 | [illegible] | 10 | [illegible] | [illegible] |
| | 36.0 | 1 | 1748.00 | 200 | [illegible] | [illegible] | [illegible] | [illegible] |
| | 26.5 | 1 | 582.64 | 1[illegible]0 | 10 | [illegible] | 6,7 | 11 |
| Total | 1260.35 | [illegible]-36<br>2-3 | 74,[illegible]76.[illegible]3 | 11[illegible]5 | [illegible]157 | 335 | [illegible]-4 [illegible]-5<br>2[illegible]-[illegible] 12-[illegible]<br>[illegible]-[illegible] | [illegible]-[illegible]<br>10-[illegible] |
| Average | 32.3 | -- | 1919.[illegible]1 | [illegible].1[illegible] | 55.[illegible] | [illegible].5[illegible] | -- | -- |

TABLE 12

MISCELLANEOUS RESULTS OF THE LAKE WASHINGTON SHIP CANAL CONGESTION SURVEY

| Question | Item | Number | Percentage |
|---|---|---|---|
| 3ai | Vessels moored in water year-round | 59 | 75.6 |
| 3aii | Vessels stored on land in winter | 7 | 9.0 |
| 3aiii | Vessels on trailers; launched & retrieved | 12 | 15.4 |
| | TOTAL | 78 | 100.0 |
| 9a | Average estimated % of underway time seaward of locks | -- | 67.4 |
| 9b | Average estimated % of time between locks & moorage | -- | 7.5 |
| | **Remaining** time cruising in fresh water | -- | 25.1 |
| | TOTAL | | 100.0 |
| 11 | Owners presently considering move to salt-water moorage | 15 | 19.2 |
| 11 | Owners already moored in salt-water | 12 | 15.4 |
| 11 | Owners not considering move to salt-water | 51 | 65.4 |
| | TOTAL | 78 | 100.0 |
| 12 | Owners which might consider moving to Salt-water | 30 | 58.8 |
| 12 | Owners which would never move to salt-water | 21 | 41.2 |
| | TOTAL | 51 | 100.0 |
| 13 | Inboard motorcraft owners preferring covered moorage | 22 | 91.7 |
| 13 | Inboard motorcraft owners preferring open moorage | 2 | 8.3 |
| | TOTAL | 24 | 100.0 |
| 13 | Other owners preferring covered moorage | 9 | 16.7 |
| 13 | Other owners preferring open moorage | 3 | 5.6 |
| 13 | Other owners not answering questions | 42 | 77.8 |
| | TOTAL | 54 | 100.0 |

**covered moorage, and the general indifference of owners of sailing** vessels to covered moorage.

## Calculation of Ownership and Operational Costs

Table 13 contains an example of the calculations necessary to convert raw data concerned with the value of time into information which may be processed by means of the mathematics developed in Chapter 4. The data used in this example was actually extracted from one of the returned questionnaires.

The first step in this calculation is to develop a figure representative of the cost to the owner of recovering his capital investment. This was done by assuming a 20 year service life and an interest rate of 5 ½ %. The capital recovery factor **(the annuity whose present value is 1)** corresponding to these arguments is equal to 0.0836. This factor multiplied by the original cost of the vessel of $4200.00 indicates that the owner of this craft pays $351.00 annually in recovering the capital he has invested in his boat. Annual operational costs are calculated simply by summing up the individual components of moorage, maintenance, fuel, storage, taxes, fees and launching charges. In this instance the sum of these operational costs is [illegible] per year.

One of the items which was unfortunately neglected in preparing the questionnaire used for this survey was insurance costs. Some owners furnished this information anyway. Most, however, did not. To compensate for this, it was assumed that since the cost of a pleasure boat represents a large investment of income, the yachtsman could afford to operate his craft

## TABLE 13

## SAMPLE CALCULATION OF THE COST OF OPERATION

### DATA

| ITEM | QUESTION | VALUE |
|---|---|---|
| Original cost | 5a | 4,200.00 |
| Estimated resale value | 5b | 2,500.00 |
| Moorage cost | 6ai | 195.00 |
| Maintenance cost | 6aii | 20.00 |
| Fuel cost | 6aiii | 20.00 |
| Storage cost | 6aiv | -- |
| Taxes & fees | 6av | 30.00 |
| Launching fees | 6avi | -- |

### CAPITAL RECOVERY

Capital recovery factor for 20 yr. at 5½% = 0.08368

Original cost = $4,200.
x 0.08368
$351. annual capital recovery cost

### OPERATION

Operation = $195
+ 20.
+ 20.
30.
= + 265. per year

### INSURANCE

2,500 x $1.60 per $100 = $40.00

### TOTAL ANNUAL COST

$351. + $265. + $40. = $656. per year

without insurance. Minimal insurance rates were therefore adopted from publications of the Nationwide Mutual Fire Insurance Company (10) and were applied uniformly to all vessels considered in this survey. In this instance a rate of $1.60 per $100.00 of value was applied to the $2500.00 that the owner of this vessel estimated as its current resale value. This gives an annual estimated insurance cost of $40.00 The total annual cost of owning and operating this vessel was then calculated by adding together the capital recovery cost, operational costs and insurance cost giving a grand total of $656.00 per year.

## Computation and Adjustment of the Value of Time

Had the results of this survey been completely representative of Seattle's boat population, indicating the correct frequency of occurrence of various types and sizes of vessels, a mean weighted figure for the value of time to Seattle yachtsmen could have been calculated by simply adding up individual calculations of annual ownership and operation costs and then dividing this figure by the sum of all usage times (see equation 1 ). Unfortunately however, the results of this survey were heavily biased in favor of sailing craft. In addition there was some variation between the average length of vessels included in this survey and the average lengths of the various classes of vessels in the general boat population. It will be remembered that when the composition of the general boat population of Seattle was investigated in Chapter 1, it was found convenient to divide the general boat population into four categories: outboard motorboats,

inboard motorboats, small (under 22 feet) sailboats, and large (over 22 feet) sailboats. Vessels which were subject to the survey incident to this thesis were divided into the same four classes (see Tables 8 through 11). After the total annual cost of ownership and operation had been calculated for each craft, these costs and the hours that the craft were operated were summed up for each of the four classes. It was then possible to calculate a weighted average value of time for each class in accordance with equation 18. These data as well as other pertinent data for each class are shown in column A through G of Table 14.

By comparing column D of Table 14 with column H we may see that the variation between the average length of boats surveyed from the average length of boats in the general boat population is relatively small and probably does not represent a major inaccuracy except in the case of large sailboats. Comparison of columns C and K of this table further indicates that the composition of boats surveyed by types of vessels is indeed at considerable variance with the composition of the general boat population.

The first adjustment undertaken in Table 14 was designed to compensate for the relatively small deviation between average lengths of boats surveyed in each category and the average length of boats in that category in the general population. The adjustment factor used (tabulated in column I) was obtained by squaring the ratio of average length of boats in that category in the general boat population to the average length of boats in that category in our survey. The value of time associated with boats in that category was then multiplied by this factor, the result being tabulated in column J.

TABLE 14

ADJUSTMENT OF LAKE WASHINGTON SHIP CANAL CONGESTION SURVEY

| A<br>Category of vessel | B<br>Number in Category surveyed | C<br>% of total by number | D<br>Average length ft. | E<br>Average annual ownership cost $ | F<br>Average annual use hr. | G<br>Weighted average cost/hr E/F $ | H<br>Average length of general boat population ft. | I<br>Length difference adjustment factor $(H/D)^2$ | J<br>Length adjusted cost/hr. $ | K<br>% in category in general boat population | L<br>Proportional partial weighted value of time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Outboard runabouts | 5 | 6.4 | 17.8 | 525.10 | 152.4 | 3.45 | 17.4 | 0.956 | 3.30 | 11.7 | 0.39 |
| Inboard Motorboats | 24 | 30.8 | 38.9 | 3541.30 | 237.21 | 14.93 | 38.8 | 0.995 | 14.86 | 54.7 | 8.13 |
| Small sailboats | 10 | 12.8 | 17.4 | 323.47 | 165.5 | 1.95 | 17.5 | 1.012 | 1.97 | 11.0 | 0.22 |
| Large sailboats | 39 | 50.0 | 32.3 | 1919.91 | 292.19 | 6.57 | 35.8 | 1.228 | 8.07 | 22.6 | 1.82 |
| TOTAL | 78 | 100.0 | -- | -- | -- | -- | -- | -- | -- | 100.0 | 10.56 |
| WEIGHTED TOTAL | -- | -- | 2456.3 | 165730.05 | 19505.06 | -- | -- | -- | -- | -- | -- |
| AVERAGE | -- | -- | 31.5 | 2124.74 | 250.06 | 8.35 | 33.3 | -- | [illegible] | -- | -- |

This procedure of adjusting the value of time on the basis of the square of the length ratio was based principally upon the experience of the author, and is difficult to justify otherwise than on a subjective basis. It is obvious however that the relationship between length and cost must be at least linear, that is when we double the length of the vessel under consideration we must at least double its cost. As a matter of fact since the object under consideration is three dimensional, there would be much justification for the argument that the cost of the vessel should be proportional to its volume and therefore that the cost should vary with the cube of the length. For this reason an adjustment based on the square of the length ratio, while undoubtedly not absolutely accurate, is at least rational and probably conservative.

The second adjustment executed in Table 14 was designed to compensate for the deviation of the percentage of boats surveyed in each category from the percentage of boats in that category in the general boat population. The percentage of boats in each category in general boat population is listed in column K. In order to make this **adjustment,** the decimal expression of these percentages were multiplied by the length adjusted value of time listed in column J, the result being tabulated in column L. This procedure weights each figure for its actual frequency of occurrence in the general boat population. The total of column J then represents the final overall average value of time to Seattle pleasure boat owners. This total indicates that the value of time to Seattle yachtsmen in general is $10.5 per hour.

### Comparison with Previous Studies

In the 1950 feasibility study of the Shilshole Bay break-water project (9), U.S. Army Engineers parallel in many respects the economic analyses undertaken herein, the point under consideration being the benefits that would accrue by the elimination of complete trips through the ship canal rather than by reductions in travel time. In the section in which pleasure craft were considered, it was estimated that the average annual cost of ownership and operation of pleasure craft amounted to $1050. An attempt was made in this study to discover how this figure related to the number of hours of use of the vessels in question. In our own study however it was discovered that the average owner used his boat about 250 hours per year. This would seem to indicate that the average boat owner spends only about $4.20 **per hour for use of** his craft. This is only 40% of the mean value of time resulting from our own survey and associated computations.

Examination of the numerical analyses utilized by Army Engineers in their study shows some minor differences in interest rates employed and so on, but there is no mechanical feature which will satisfactorily account for the large variation between the figures obtained in that study and in the study undertaken pursuant to this thesis.

Table 14, at the bottom of column F, shows a simple average annual ownership and operation cost of $2124.74. This figure divided by the average annual hours of use would give a value of time of about $8.55 per hour. Note this is an unadjusted figure. This is still almost twice the value based on Army Engineers work. In view of this large and seemingly inexplicable difference, it would be no more than prudent to suggest that the subject of the value of time requires further investigation.

# CHAPTER VI

# SAVINGS IN TRAVEL TIME

## Review of Methodology

It will be remembered that in chapter 4, during the development of the theory and methodology necessary to this study, equation 15 was adopted to express the mathematics required for the economic analyses of the facilities proposed herein.

(15) $J = KV\Delta t$

this relationship holds the justifiable cost of an additional facility to be equal to a constant multiplied by the value of time, multiplied again by the time savings occasioned by use of the proposed facility. At this point in the development of our investigation, both the constant and the value of time necessary to this equation are available for use. the one in table 6, the other in table 14.

It will also be remembered that an equation was developed expressing the magnitude of travel time savings in terms of the difference between the transit time through the proposed new facility and that through the present large lock multiplied by the number of vessels that would use the new facility in preference to the large lock.

(20) $\Delta t = N(t_l - t_f)$

The task to be undertaken in this chapter is the quantification of the savings in travel time that would be realized through the installation of one or more of the proposed facilities. This will involve the determination of the transit time associated with the present large lock, the estimation of the transit time that may be expected to be associated with each of the proposed new facilities, and the estimation, for each of these

facilities of the amount of traffic that may be expected to use that facility in preference to the present installation. In addition it will be remembered that in Chapter 3 when the construction of an additional lockage facility was first proposed, the consideration of exactly what size lock should be built was deferred until later. This question also will be considered in this chapter.

## Lock Record Types

There are five distinct types of records available for study at Hiram M. Chittenden Locks. These include the following: Waterway Traffic Report, Register of Vessel Traffic Through Locks or Waterways, Report of Lockages and Number of Vessels, Classification of Vessels Passing the Locks, and the Annual Summary of Vessel Classification.

The Waterway Traffic Report is the form, referred to frequently in Chapter 3, that must be filled out by each vessel passing through the locks. Information available on these forms includes the name of each vessel passing the locks, its owner, destination, cargo, draft, displacement, etc. These records are the basis for all more compact compilations of lockage data and while relatively detailed, unfortunately omit much information that would be of considerable interest in studies of lock operations. No use was made of these records in the preparation of this report.

The Register of Vessel Traffic Through Locks or Waterways is a compilation of Waterway Traffic Reports for each lockage through each lock. These records contain the name or number of each vessel passing through the locks, an indication of its type, its displacement and the

time of opening of the lock gate at upper and lower pool level for the transit in which each group of vessels passed the locks. Since transportation costs should certainly be a function of data recorded in detail in this record type (vessel type, displacement and transit time), it should be possible, using these records, to make extremely accurate calculations of transportation costs for every type and size of vessel passing the locks. However, because of the vast volume of records that must be considered even for a single year, such calculations would, even with the aid of electronic data processing, be extremely time consuming and onerous. Such a calculation is indeed far beyond the scope of this thesis, more compact record formats being utilized for our purposes herein except for the discussions of transit time and lock efficiency later in this chapter. It is probable that this is the type of record which would form the basis of an extended study of the ship canal system of the sort proposed in the final chapter of this report.

In the report of Lockages and Number of Vessels, the number of lockages with vessels, the number of lockages without vessels, and the number of vessels passing through the locks is totaled up for each lock during each of three shifts of each day. Data extracted from these records was employed in the succeeding section concerned with the determination of the number of vessels that may be expected to use new, rather than presently existing, facilities.

The classification of Vessels Passing the Locks is a tabulation for each of the two locks for each day, of the total number and displacement of vessels in each of several categories passing the locks. Categories considered include ships, barges, tugs, small craft, fishing boats,

U. S. vessels, and foreign vessels. It is data from these records that is used as the basis for estimates made herein of the number of vessels that may be expected to use the proposed facilities in preference to facilities already in existence.

The Annual Summary of Vessel Classification is a tabulation and summary by months of the more detailed data contained in the previously mentioned Classification of Vessels Passing the Locks. Data extracted from these records was used in Chapter 1 (see Table 4 and Figure 4) to describe the overall annual fluctuation of traffic in the ship canal system.

Determination of Size of Proposed Additional Lock

When the possibility of providing an additional lock was first proposed in Chapter 3, it was mentioned that there are conflicting criteria militating one against the other concerning the selection of the most desirable size for such a facility. On the one hand we want a lock which will pass traffic through as rapidly as possible thus holding travel time accruing to vessels transiting the facility to a minimum; while on the other we want a facility large enough to be capable of absorbing the large peak loads which occur on weekends and holidays. The very existence of the present installation provides us with the best of all possible data necessary to select the correct size for an additional lock. The existing large lock, while not the largest in the world, is certainly one of the larger of such installations in existence and the small lock is very small indeed. Whatever size of lock we select for our additional facility cannot lie far outside the limits delineated by the present establishment.

In the first four columns (A,B,C,D) of Tables 15 and 16 are tabulated data extracted from the previously mentioned Register of Traffic Through Locks or Waterways. Table 15 contains data applicable to the large lock while Table 16 tabulates data concerning the smaller facility. The observations listed in these Tables were selected more or less at random from the available records to cover the range from lockages containing very few vessels to lockages during which the lock chambers were severely crowded. Column A of each table lists the number of vessels in the chamber of the appropriate lock during a specific transit. Columns B and C list the times of opening of the lock gates for ingress of vessels into the locks and egress of vessels from the locks after completion of the transit. The difference between these two times is the actual time occupied in lifting and lowering the vessels involved and is tabulated in Column D. To each of the times listed in Column D is added the minimum time necessary to return the water level in the lock chamber to its original position thus completing the cycle (10 minutes for the large lock and 5 minutes for the small lock). The sum of Columns D and E is then the full cycle length and is tabulated in Column F. Dividing Column A (number of vessels in the chamber) by Column F (cycle length in minutes) and multiplying by 60 gives the rate of traffic flow in vessels per hour and is tabulated in Column G. Various data from these tables are presented graphically in Figures 10, 11 and 12.

TABLE 15

RANDOMLY SELECTED TRANSITS - LARGE LOCK

| A<br>Number of Vessels in Chamber | B<br>Time of Opening Gates for Vessel Ingress | C<br>Time of Opening Gates for Vessel Egress | D<br>Actual Lift/Lower Time Minutes | E<br>Return Time Minutes | F<br>Cycle Length Minutes | G<br>Traffic flow Vessels/hour |
|---|---|---|---|---|---|---|
| 89 | 1655 | 1755 | 60 | 10 | 70 | 76 |
| 78 | 1635 | 1715 | 40 | | 50 | 94 |
| 66 | 1515 | 1605 | 50 | | 60 | 72 |
| 72 | 1620 | 1710 | 50 | | 60 | 72 |
| 68 | 1725 | 1800 | 35 | | 45 | 91 |
| 69 | 1815 | 1855 | 40 | | 50 | 83 |
| 0 | 1900 | 1910 | 10 | | 50 | 34 |
| 24 | 2005 | 2100 | 55 | | 55 | 26 |
| 15 | 2125 | 2200 | 35 | | 35 | 26 |
| 10 | 0750 | 0800 | 10 | | 20 | 30 |
| 4 | 0945 | 0955 | 10 | | 20 | 12 |
| 34 | 1130 | 1220 | 50 | | 60 | 34 |
| 25 | 1440 | 1515 | 35 | | 45 | 33 |
| 36 | 1605 | 1645 | 40 | | 50 | 43 |
| 58 | 1630 | 1720 | 50 | | 60 | 58 |
| 88 | 1730 | 1835 | 65 | | 75 | 70 |
| 40 | 1850 | 1950 | 60 | | 70 | 34 |
| 80 | 1610 | 1700 | 50 | | 60 | 80 |
| 74 | 1710 | 1755 | 45 | | 55 | 81 |
| 66 | 1805 | 1850 | 45 | 10 | 55 | 72 |

TABLE 16

RANDOMLY SELECTED TRANSITS - SMALL LOCK

| A<br>Number of Vessels in Chamber | B<br>Time of Opening Gates for Vessel Ingress | C<br>Time of Opening Gates for Vessel Egress | D<br>Actual Lift/Lower Time Minutes | E<br>Return Time Minutes | F<br>Cycle Length Minutes | G<br>Traffic Flow Vessel/hour |
|---|---|---|---|---|---|---|
| 16 | 1035 | 1055 | 20 | 5 | 25 | 38.4 |
| 14 | 1120 | 1145 | 25 | 5 | 30 | 28 |
| 2 | 2335 | 2345 | 10 | 5 | 15 | 8 |
| 1 | 0015 | 0020 | 5 | 5 | 10 | 6 |
| 1 | 0230 | 0240 | 10 | 5 | 15 | 4 |
| 2 | 0510 | 0515 | 5 | 5 | 10 | 12 |
| 3 | 0630 | 0645 | 15 | 5 | 20 | 9 |
| 4 | 0740 | 0750 | 10 | 5 | 15 | 16 |
| 5 | 0835 | 0850 | 15 | 5 | 20 | 15 |
| 8 | 1040 | 1050 | 10 | 5 | 15 | 32 |
| 11 | 1115 | 1135 | 20 | 5 | 25 | 26.4 |
| 8 | 1305 | 1320 | 15 | 5 | 20 | 24 |
| 10 | 1400 | 1420 | 20 | 5 | 25 | 24 |
| 11 | 1825 | 1840 | 15 | 5 | 20 | 33 |
| 7 | 1635 | 1645 | 10 | 5 | 15 | 28 |

Equation 20 indicates that any savings in travel time that we may reap from a new installation will, for a given magnitude of transit time through the present installation, be inversely proportional to the transit time through the new facility. This means that it will be inversely proportional to the cycle length, for as we shall see later (at least for locks) transit time is approximately 1.5 times the cycle length. With this fact in mind and mindful also that the criteria we are attempting to satisfy demand maximum traffic flow rate combined with minimum transit time or cycle length, let us examine Figure 10.

This figure is a plot of vessels per cycle against cycle length. It may easily be seen that there is considerable variation from any mean curve. The curves shown for the two locks however, represent adequately the performance of these locks. Several operational characteristics of the present installation are apparent in this presentation. Note that the greatest number of vessels shown to ever have passed through the small lock in a single cycle is 16 and that the mean curve extends only as far as 14 vessels per cycle. The mean curve for the large lock on the otherhand, extends as high as 89 vessels per cycle. Note also that the mean curves, and indeed all plots, terminate at roughly the 10 and 20 minute ordinates of cycle length. This is caused by the fact that the minimum time required for simple hydraulic operation of the locks is five and ten minutes each way for the small and large locks respectively. Other features worth mentioning are the verticality of the mean curve for the large lock between the abcissas of 30 and 75 vessels per cycle and the displacement to the left of the mean curve for the small lock from that for the large lock.

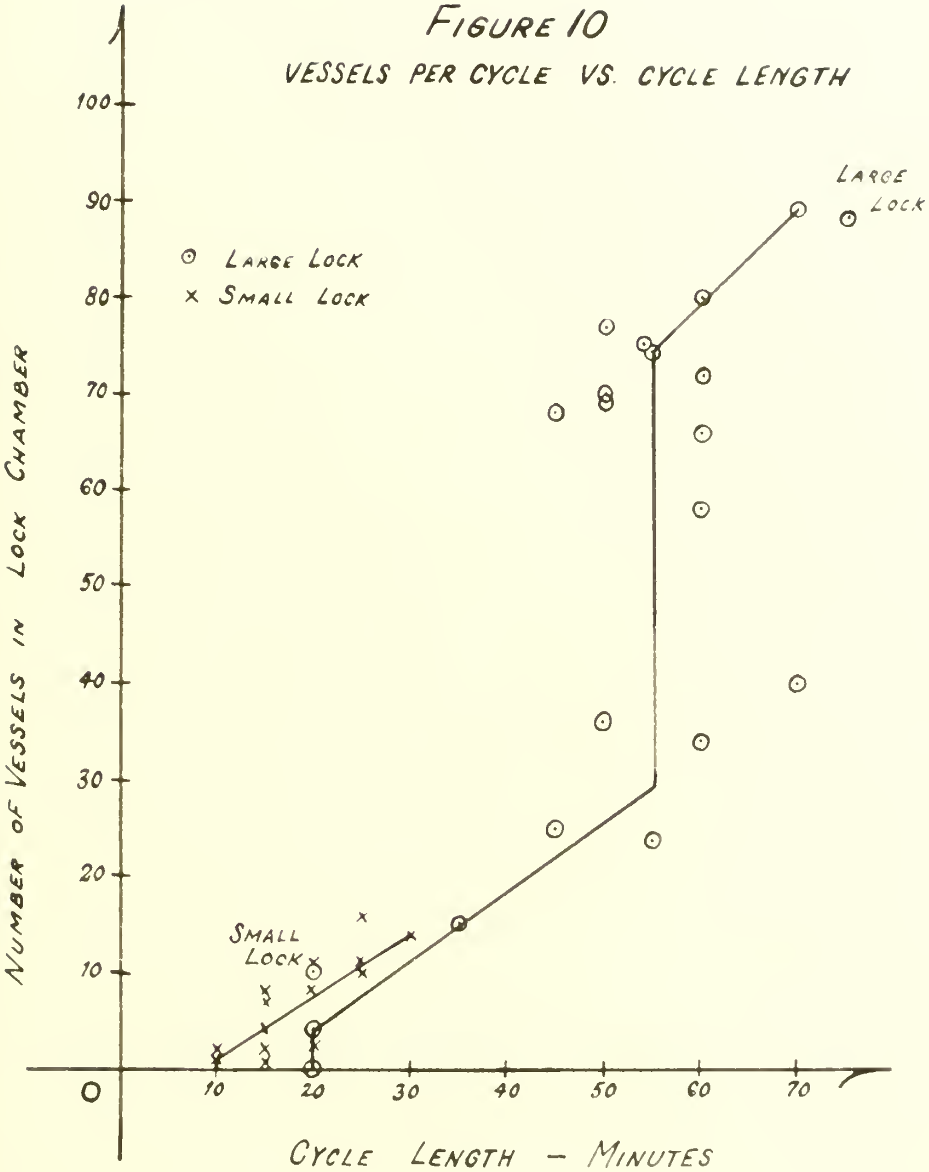


FIGURE 10

VESSELS PER CYCLE VS. CYCLE LENGTH

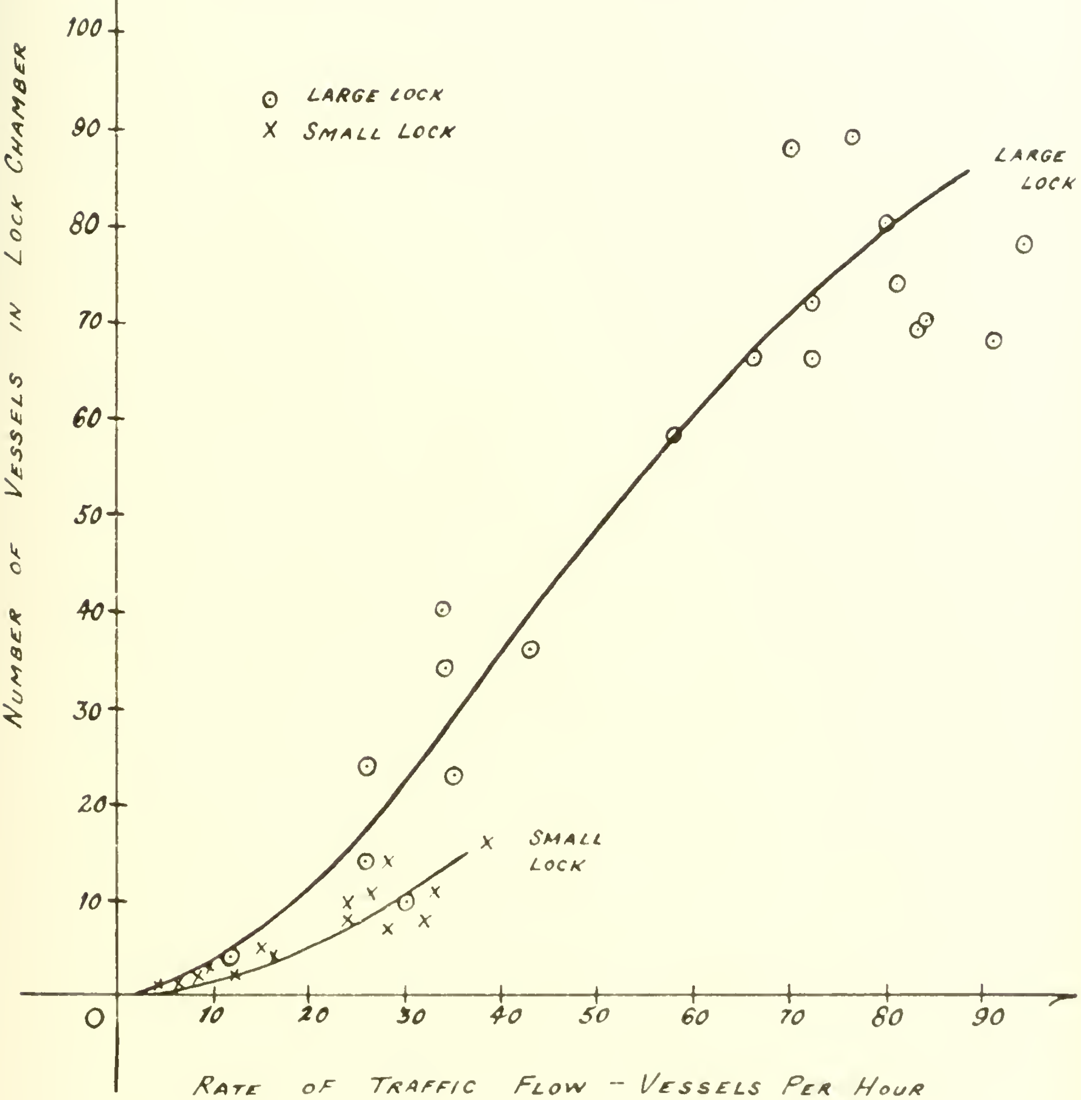
Three facts may be induced from these observations. First there is the rather obvious point that the large chamber of the large lock confers a greater capacity to pass traffic. Secondly we may infer that this great chamber capacity carries with it the penalty of disproportionately increased cycle length. Lastly we may see that the small lock, within its capacity, operates more efficiently as is witnessed by the displacement of the mean curve for the small lock to the left.

Figure 11 plots the number of vessels passed through the locks in a single cycle against the rate of traffic flow, in vessels per hour, achieved thereby. In this presentation the essential efficiency and superiority of the smaller of the two installations is even more obvious. You may note that for any given number of vessels in a single lockage, the small lock is able to achieve a greater rate of traffic flow. It is also worthwhile mentioning here that the maximum practical rate of traffic flow which the smaller installation seems to be capable of handling is about 30 vessels per hour at chamber loads of 10 vessels per cycle. Referring now to Figure 12 we see that when rate of traffic flow is plotted against cycle length(which you will remember is inversely proportional to travel time savings) we may see the efficiency of the small lock again demonstrated. Note that at rates of flow of about 30 vessels per hour, the small lock is averaging about 22 minutes per cycle. In order to achieve the same rate of flow, cycles in the large lock must run about 49 minutes on the average.

If we must build a new lock to handle traffic loads in the Lake Washington Ship Canal, then what we want is a lock that retains (or even improves upon) the operational efficiency of the present small lock,

FIGURE 11

VESSELS PER CYCLE VS. TRAFFIC FLOW



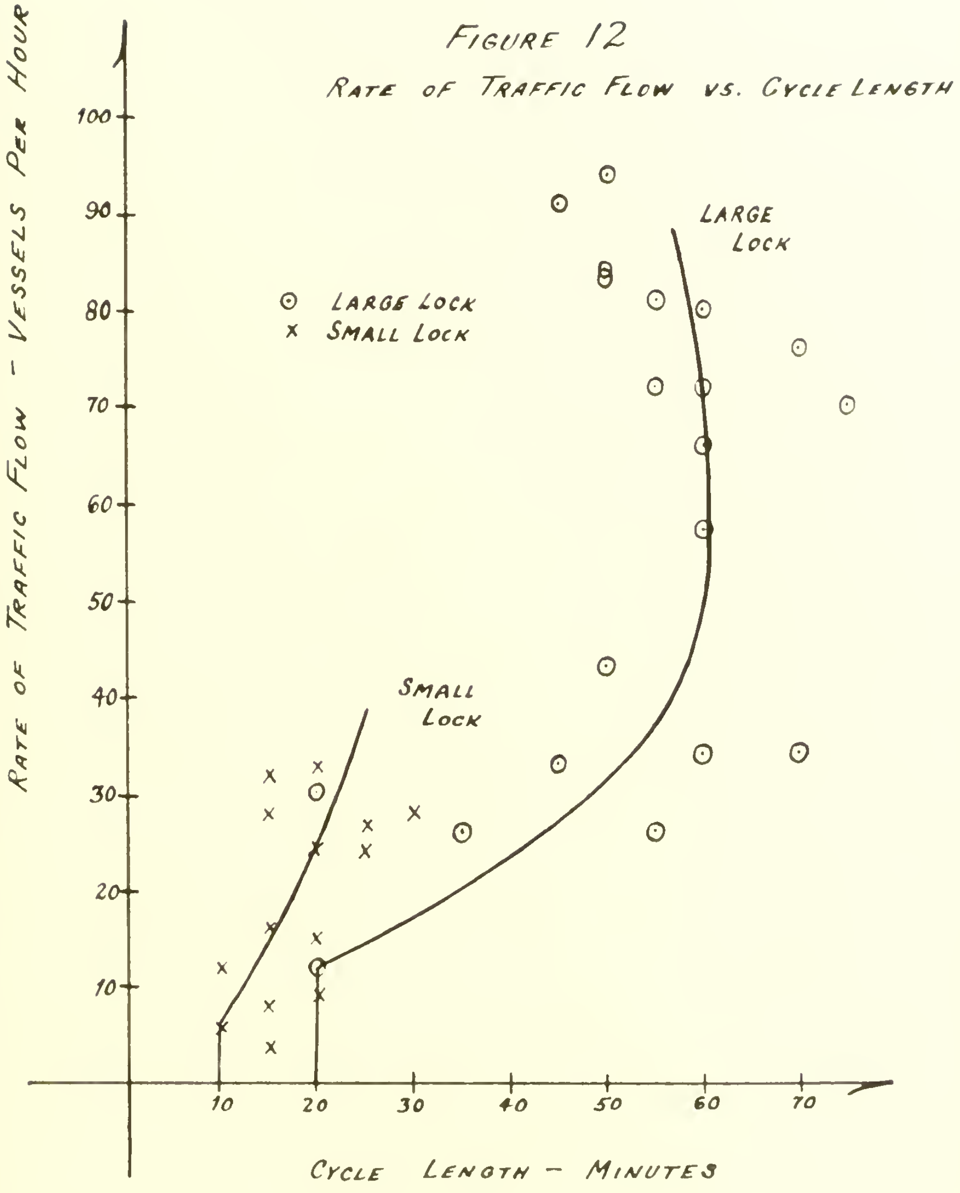


FIGURE 12

RATE OF TRAFFIC FLOW VS. CYCLE LENGTH

but which will at the same time enable us to achieve the maximum rates of traffic flow of which the large lock is capable. By this time it whould be obvious that the most desirable type of installation would be one more or less similar to the present small lock. As we saw in Figure 12, we may expect from such an installation a practical maximum traffic rate of about 30 vessels per hour at a cycle length of 20 minutes. To match the maximum traffic handling capacity of our large lock we would need at least two such installations operating simultaneously, situated parallel to one another outboard of the present small lock. The next step of thought beyond this is, instead of imagining two additional separate small locks, to conceive of a single wide lock-chamber having two or more traffic lanes and the requisite number of sets of multiple lock gates. Such an arrangement might possibly be made to operate even faster than 30 minutes per cycle (by limiting the number of vessels using each lane to even less than 10 vessels) while simultaneously providing traffic handling capacity in excess of that presently available in the large lock.

The principal disadvantage of this type of lock would be inefficient use of water at light or intermediate rates of traffic flow and inability to achieve further efficiencies of operation by means of staggering the cycles of multiple small locks so that one or another is always in the process of accepting traffic, etc.

In order to make a reasonable definitive examination of the economic possibilities opened up by installations of the type discussed in the preceding paragraphs, all of these possibilities will be examined.

To rephrase this more precisely, justifiable costs of the following installations will be calculated; first an additional, single-chambered small lock of approximately the same dimensions as the present installation; second, a lock having two separate chambers each of the same dimensions of the present small lock; and third a wide, single chambered, multi-lane lock having a traffic capacity of 60 vessels per hour or more.

## Determination of Transit Time Through Large Lock

There is no problem in establishing a value for $t_1$, the transit time through the large lock required for use in equation 20. Figure 10 shows quite clearly the strong tendency of the cycle length to vary between relatively narrow limits throughout a large range of chamber loadings. Since the phenomena which we are considering, that of forced passage through the large lock due to overcrowding of the smaller facility, occurs only during high traffic days and in times of great traffic density, it is quite reasonable to assume that a 55 minute cycle length will be by far that most frequently encountered during these times. Note that at chamber loadings greater than about 75 vessels per cycle, cycle length again seems to increase. Any error that this causes may, we hope, be balanced out by the shorter cycle length experienced at chamber loadings less than 30 vessels per cycle.

Let us now turn our attention once again to the pattern of operation of the locks during periods of heavy traffic. During these times there is a constant stream of vessels arriving at the locks for passage. If we assume a constant arrival rate and assume that the arrival rate never surpasses the maximum rate of traffic flow of which

the two locks are capable, then we may say that the average vessel arriving for passage through the large lock must wait half a cycle of that lock before being admitted to the chamber for passage. Looking at this another way, a vessel which arrives at the lock just as the gates close must wait a full cycle before it is admitted into the lock chamber for passage, while a vessel arriving just as the lock gates open to admit a chamber load is admitted immediately. The mean wait then is half a cycle. On this basis the transit time through the large lock during periods of heavy traffic may be said to be 1.5 times the cycle length.

In actuality this is somewhat of a simplification. The rate of arrival of vessels at the lock is never constant but varies continually; the maximum traffic handling capacity of the combined locks is frequently exceeded so that some vessels must wait more than a full cycle for passage; and the vessel next in line for passage after the last vessel for the current cycle has been admitted into the large lock seldom has to wait a full cycle for passage but rather is usually able to pass through the small lock during it cycle. These factors interact quite complexly and the author doubts that they are subject to theoretical analysis.

If a more detailed study of this problem were undertaken, it would probably involve continuous observation of traffic flow patterns in order to make a precise determination of the travel time experienced by each individual vessel passing the locks. This of course would have to be done either photographically, pictures being taken at say, one minute intervals, or by means of a team of observers continuously on duty at the locks.

For our purposes here however, we will assume that the mean vessel passing through the locks in a given cycle accrues travel time in the amount of 1.5 times the cycle length. The value of $t_1$ then, should equal 1.5 multiplied by 55 divided by 60 or, 1.375 hours.

## Determination of $t_f$ and N

In order to equip ourselves completely with entering arguments for use in equation 20, it is now necessary that we estimate both the transit time through those facilities which we have proposed and the number of vessels which will use one or another of those facilities in preference to the large lock. To facilitate this, Table 17 presents a tabulation, adopted from various of the records available at the locks, summarizing the number of pleasure craft using the locks during the past six years and showing the distribution of days of varying traffic intensity. Since both the transit time and the number of vessels diverted are interdependent, it will be convenient to consider both of these quantities simultaneously for each variety of installation being investigated.

## Marine Railways

It will be remembered from Chapter 5 that the proposed marine railway installation was to be oval in form so that the boat conveying cars, once emptied of their load, might pass back to pick up another vessel via a track in the opposite direction, thus insuring an efficient one-way circulation of cars on the tracks. This system obviously may be extended to a

## TABLE 17

## PLEASURE CRAFT LOCKAGE DATA

| A<br>Year | B<br>Pleasure* Craft Transiting Small Lock | C<br>Pleasure* Craft Transiting Large Lock | D<br>Total Pleasure Craft Through Both Locks | E<br>Day's Pleasure Craft Transiting Large Lock Numbered Between<br>0 & 10 | F<br><br>11 & 50 | G<br><br>51 & 100 | H<br><br>101 & 200 | I<br><br>201 & 300 | J<br><br>301 & 400 | K<br><br>401 & 500 | L<br><br>501 & 600 | M<br><br>601 & Over | N<br>Pleasure Craft Transiting Large Lock on Days Over 601 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1958 | 32571 | 21097 | 53668 | 126 | 77 | 20 | 19 | 11 | 12 | 5 | 3 | 5 | 691,621,630,618,1031** |
| 1959 | 31760 | 15789 | 47549 | 168 | 65 | 22 | 16 | 15 | 7 | 5 | 1 | 1 | 613 |
| 1960 | 31383 | 16309 | 47692 | 168 | 73 | 13 | 18 | 14 | 9 | 4 | 1 | 3 | 685,603,605 |
| 1961 | 29808 | 17062 | 46870 | 167 | 66 | 23 | 13 | 21 | 11 | 2 | 3 | 0 | -- |
| 1962 | 32103 | 15645 | 47748 | 144 | 102 | 19 | 26 | 15 | 6 | 2 | 2 | 0 | -- |
| 1963 | 33737 | 15460 | 49197 | 152 | 58 | 24 | 21 | 14 | 11 | 2 | 2 | 0 | -- |

* These figures do not include pleasure craft of foreign origin and will therefore differ somewhat from the figures previously presented in Table 6.

** Occurred when small lock out of commission! However, availability of additional facility would obviate necessity for all traffic to pass large lock.

multi-track layout. Boats would travel in the predominant direction of traffic flow over all but one of the available sets of tracks and the remaining set would be used for car return, appropriate connections being made by switches. Systems of two tracks (the minimum number), three and four tracks will be considered. Consideration of the minimum layout will give us the minimum justifiable cost of any marine railway installation, while consideration of a four-track layout is desirable since the capacity of such an arrangement would approximate the capacity of a single chambered small lock.

As far as capacity goes, the controlling factor, as was mentioned previously, for a marine railway installation is the probable excess of time required as each vessel is loaded onto a car. As was mentioned in Chapter 3 it is virtually inconceivable that vessels could be loaded on cars at a rate more rapid than one each five minutes, thus limiting a single lane of track to a capacity of twelve vessels per hour. Since the time that would be spent transiting this kind of installation would be a combination of loading time plus unloading time plus actual time being drawn up and over the railway, some consideration must be given to the length of the railway, which is principally dependent upon the grade employed.

Slipways designed for major vessels are seldom set on grades in excess of 3%. We are not restricted to such flat slopes as these for the handling of small craft. Boat launching ramps for instance, are commonly constructed on slopes of 15%. In order both to minimize the length of track necessary on either side of the dam, thus minimizing the size of structure required to support the railway, and to reduce transit time to

a minimum, we would like to have as short a run of track as possible on either side of the dam. This means we want to use as steep a grade as we possibly can. Assuming that motive power for the cars of such a marine railway would be provided by a cable arrangement similar to that used for the San Francisco cable cars, there will be no problem in providing grades far in excess of those that could be tolerated by passengers in the vessels transiting the facility. Passenger comfort will be the most important factor limiting the maximum usable grade. For the purposes of this investigation we will assume a grade of 20%.

Referring to Figure 5 and Table 5 we see that the tide on the seaward side of the dam fluctuates from about four feet below datum to 15 feet above; the crest of the dam is at an elevation of 34 feet and the upper pool is maintained at a level of approximately 21 feet. The mean pool level on the seaward side will be about 5.5 feet above datum. The tracks cannot pass over the dam precisely at the elevation of the crest. There will have to be some allowance for structural support and operating machinery. Allowing 3.5 feet clearance over the dam crest for this, vessels transiting the facility will have an average rise of about 32 feet from lower pool level to the crest and a rise of 16.5 feet from the upper pool to the crest for a total rise and fall of about 48.5 feet. In order not to strain the credibility of our limits of accuracy, we will round this off to 50 feet of rise and fall. At a grade of 20%, which is equal to five feet of run for each foot of rise, the facility will occupy a total of 250 feet horizontally and the slant distance which would need to be traversed would be approximately 255 feet.

If we assume a rate of movement in the slant plane of five feet per second (a speed about equivalent to a fast walk) a vessel could travel the length of the tracks in about 51 seconds. Rounding this off to one minute and assuming an additional minute of reflotation time, we arrive at the conclusion that a vessel should be able to transit such a marine railway in approximately seven minutes. For the marine railway installation then, we will use $t_1$ equal to 7/60 or 0.117 hours. This value is recorded in Table 20. Since the time it will take for a vessel to transit a marine railway installation is independent of the number of lanes in operation simultaneously, this same transit time will hold no matter how many lanes of track are available for use.

In order to estimate the number of vessels that would be diverted from the present large lock to the new facility we will use the data available to us in Table 17. Column E through M of this table list the number of days in the past six years during which the number of pleasure craft transiting the large lock was between the limits specified in the column headings. The basic assumption that will be used to convert this data into estimates of the number of craft diverted to the proposed facility will be that the proposed facility will operate at its maximum rate of traffic flow for a period of time equivalent to that necessary for the present large lock to pass the same amount of traffic at a rate of traffic flow typical of a high capacity day. Additional assumptions will be that the rate of traffic flow achieved through the large lock varies more or less in proportion to the total amount of traffic passed and that on days of relatively low traffic, the traffic will be spread out sufficiently

for our proposed facility to handle the entire load.

Based on these assumptions, the figures shown in columns E through M of Table 17 are converted into estimated numbers of vessels diverted to the various sizes of marine railway by means of a more or less logical procedure which is described in detail in Appendix I. Each estimate is listed in Table 18 and the total estimated diverted vessels for each of the years under consideration is calculated and entered in the appropriate column (D through F) of Table 20.

Beltways

As was mentioned in Chapter 3, considerably greater rates of traffic flow can probably be realized over beltways than over marine railways since little or no maneuvering need be done for a vessel to enter the beltway. The controlling aspect of such an installation would probably be the provision of enough distance between successive vessels on the belt so that there would be no danger of collision at the point of re-entry into the water. In consequence of this, we will assume a one minute separation between boats transiting the small single beltway, and a two minute separation between larger vessels transiting the double beltway. Based on these assumptions a traffic flow of 60 vessels per hour could be achieved over the small beltway and a flow of 30 vessels per hour over the larger double beltway.

Using the same 20% grade assumption as was used for the marine railway, we find that the beltway would be of approximately the same length.

## TABLE 18

## ESTIMATE OF VESSELS DIVERTED TO MARINE RAILWAY

| A<br>Facility | B<br>Table 17 Column | C<br>Mean Traffic Above Incidental | D<br>Vessels per day Diverted | E<br>1958 | F<br>1959 | G<br>1960 | H<br>1961 | I<br>1962 | J<br>1963 |
|---|---|---|---|---|---|---|---|---|---|
| Two lanes of track (one Traffic & one return) | E | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F | 20 | 20 | 1540 | 1300 | 1460 | 1320 | 2040 | 1160 |
| | G | 65 | 22 | 440 | 484 | 286 | 506 | 418 | 528 |
| | H | 140 | 44 | 336 | 704 | 792 | 572 | 1144 | 924 |
| | I | 240 | 55 | 605 | 825 | 770 | 1155 | 825 | 770 |
| | J | 340 | 77 | 924 | 539 | 693 | 847 | 462 | 847 |
| | K | 440 | 99 | 495 | 495 | 396 | 198 | 198 | 198 |
| | L | 540 | 121 | 363 | 121 | 121 | 363 | 242 | 242 |
| | M | -- | -- | 731 | 132 | 418 | -- | -- | -- |
| TOTALS | | | | 5434 | 4600 | 4936 | 4961 | 5329 | 4669 |
| 3 lanes of track | E | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F | 20 | 20 | 1540 | 1300 | 1460 | 1320 | 2040 | 1160 |
| | G | 65 | 44 | 880 | 968 | 572 | 1012 | 336 | 1056 |
| | H | 140 | 88 | 1672 | 1408 | 1584 | 1144 | 2288 | 1848 |
| | I | 240 | 110 | 1210 | 1650 | 1540 | 2310 | 1650 | 1540 |
| | J | 340 | 154 | 1848 | 1078 | 1386 | 1694 | 924 | 1694 |
| | K | 440 | 198 | 990 | 990 | 792 | 396 | 396 | 396 |
| | L | 540 | 242 | 726 | 242 | 242 | 726 | 484 | 484 |
| | M | -- | -- | 1562 | 264 | 836 | -- | -- | -- |
| TOTALS | | | | 10428 | 7900 | 8412 | 8602 | 8618 | 8178 |
| 4 lanes of track | E | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | F | 20 | 20 | 1540 | 1300 | 1460 | 1320 | 2040 | 1160 |
| | G | 65 | 65 | 1300 | 1430 | 845 | 1495 | 1235 | 1560 |
| | H | 140 | 132 | 2508 | 2112 | 2376 | 1716 | 3432 | 2772 |
| | I | 240 | 165 | 1815 | 2475 | 2310 | 3465 | 2475 | 2310 |
| | J | 340 | 231 | 2772 | 1617 | 2079 | 2541 | 1386 | 2541 |
| | K | 440 | 297 | 1485 | 1485 | 1188 | 594 | 594 | 594 |
| | L | 540 | 336 | 1008 | 336 | 336 | 1008 | 672 | 672 |
| | M | -- | -- | 2343 | 396 | 1254 | -- | -- | -- |
| TOTALS | | | 14771 | 14771 | 11151 | 11848 | 12139 | 11834 | 11609 |

Assuming again a five foot per second velocity in the slant plane along the beltway, transit time over the smaller beltway would be again approximately one minute. It is thought better, since the larger double beltway would be handling a larger and probably less resilient vessel, to reduce the assumed speed for this dual installation to half that of the smaller beltway, or 2.5 feet per second. This would result in a transit time of twice that for the smaller belt or about 2 minutes. These are equivalent to transit times of about 0.017 hours for the single belt and 0.033 hours for the dual arrangement, giving difference in transit time between these facilities and the presently installed large lock of 1.35 and 1.342 hours respectively.

Estimation of the number of vessels during the past several years that would be diverted from the present large lock to the two sizes of beltway is carried out in Table 19. In columns A and B of this table are listed the year and the number of pleasure craft that transited the large lock during these years. In columns C and D are shown the number of days that the number of pleasure craft transiting the large lock was less than ten and over eleven. For days during which the number of craft transiting the large lock was less than ten, the mean incidental traffic through the lock was assumed to be five vessels per day. On days when this traffic was greater than eleven vessels per day, the incidental traffic was again assumed to be ten vessels per day. Based on these assumptions, columns E and F were tabulated by multiplying column C by five and column E by ten, the line totals of columns E and F being shown in column G. Subtracting this figure from the number of pleasure craft transiting the large

TABLE 19

ESTIMATE OF VESSELS DIVERTED TO BELTWAYS

| A<br>Year | B<br>Pleasure Craft Transiting Large Lock | C<br>Days Pleasure Craft Transiting Large Lock Numbered | D | E<br>Incidental Traffic Through Large Lock | F | G | H<br>Non-Inciden-tal Traffic | I<br>% of out-boards Plus Small Sailboats | J<br>No. of Vessels Diverted to single Beltway | I<br>% of Cabin Cruisers plus large Sail-boats | L<br>No. of Vessels Diverted Dual Beltway |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Less Than 10 | Over 11 | On Days Less Than 10 | On Days Over 11 | Total | | | | | |
| 1958 | 21097 | 126 | 152 | 630 | 1520 | 2150 | 18947 | 22.7 | 4301 | 77.3 | 14646 |
| 1959 | 15789 | 168 | 132 | 840 | 1320 | 2160 | 13629 | | 3094 | | 10535 |
| 1960 | 16309 | 168 | 135 | 840 | 1350 | 2190 | 14119 | | 3385 | | 10734 |
| 1961 | 17062 | 167 | 139 | 835 | 1390 | 2225 | 14837 | | 3368 | | 11469 |
| 1962 | 15645 | 144 | 172 | 720 | 1720 | 2440 | 13205 | | 2298 | | 10907 |
| 1963 | 15460 | 152 | 132 | 760 | 1320 | 2080 | 13380 | | 3037 | | 10343 |

lock for the entire year gives the non-incidental traffic for the year as tabulated in column H.

It will be remembered that when in Chapter 3, the beltways were originally discussed, it was mentioned that a single beltway could accomodate only more or less flat bottomed vessels, that is, outboard motorboats and small sailboats. The dual beltway arrangement was introduced to overcome this defect, but because of the necessary split between belts it was felt that this type of beltway would not accomodate the smaller class of pleasure boats.

Returning once again to Table 4, it may be determined that outboard motorboats and small sailing craft amount to 11.7% and 11.0% of the boat population by number respectively, the total of the two types being 22.7%. Obviously the remaining 77.3% of the boat population includes the larger classes of pleasure craft. By multiplying these percentages (shown in column I and K) by the non-incidental traffic listed in column H we arrive at the total divertable traffic for the six years under consideration as shown in column J and L.

Remembering that the single beltway has a capacity of 60 vessels per hour, it is readily apparent that this sort of facility is completely capable of handling the relatively small portion of the total traffic represented by the figures in column J of Table 19. Therefore these figures are entered in Table 20 without further manipulation. In the same way when we examine column L, the number of vessels that could possibly be diverted from the large lock to a dual beltway, remembering that the capacity of this beltway is 30 vessels per hour, we see that in comparison

TABLE 20

ESTIMATE OF TRAVEL TIME SAVINGS

| Facility | Transit Time Hours | Difference in Transit Time Hours | Total Number of Vessels Diverted to New Facility | | | | | | Total Savings in Travel Time Vessel Hours | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 |
| Large Lock | 1.375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Two Lane Marine Railway | 0.117 | 1.258 | 5984 | 4600 | 4936 | 4961 | 4449 | 5549 | 7527 | 5787 | 6209 | 6241 | 5597 | 6981 |
| Three Lane Marine Railway | 0.117 | 1.258 | 10428 | 7900 | 8412 | 8602 | 7738 | 9056 | 13118 | 9938 | 10582 | 10821 | 9734 | 11392 |
| Four Lane Marine Railway | 0.117 | 1.258 | 14771 | 11151 | 11848 | 12139 | 10954 | 12489 | 18582 | 14028 | 14905 | 15271 | 13780 | 15711 |
| Single Beltway | 0.017 | 1.358 | 4301 | 3094 | 3385 | 3368 | 2298 | 3037 | 5841 | 4202 | 4596 | 4573 | 3121 | 4124 |
| Dual Beltway | 0.033 | 1.342 | 14646 | 10535 | 10734 | 11469 | 10907 | 10343 | 19655 | 14138 | 14405 | 15391 | 14637 | 13880 |
| Small Lock | 0.42 | 0.955 | 12309 | 9292 | 9873 | 10115 | 9128 | 10407 | 11755 | 8874 | 9429 | 9660 | 8717 | 9939 |
| Double Small Lock | 0.39 | 0.985 | 18947 | 13629 | 14119 | 14637 | 13205 | 13380 | 18663 | 13425 | 13907 | 14417 | 13007 | 13179 |
| Multi-Lane Lock | 0.42 | 0.955 | 18947 | 13629 | 14119 | 14637 | 13205 | 13380 | 18094 | 13016 | 13484 | 14169 | 12611 | 12778 |

to the figures generated in Table 1[illegible] for a 36 vessel marine railway installation, the figures in column L compare quite closely with those estimated by an entirely different procedure. Therefore the values listed in column L of Table 19 are also entered directly in the appropriate spaces of Table 20 without additional manipulation.

Locks

Assuming that our proposed additional small locks have the same general chamber dimensions and operating characteristics as the present smaller installation, reference to Figure 12 shows that traffic flows on the order of 30 vessels per hour could be achieved through such a facility at a cycle length of 20 minutes per cycle. It will be remembered that for a single lock, the transit time was said to be equal to 1.5 times the cycle length. This will not be true for the proposed additional one or two small lock chambers. Interaction of these proposed facilities one with the other and with the present small lock will reduce the effective transit time through the total facility to less than 1.5 times the cycle length. Using the same line of reasoning employed in the original deduction of the 1.5 cycle length relationship, and assuming staggered cycling of two parallel small locks, we may see that a vessel approaching such a double installation would not have to wait a full half cycle before being admitted to the lock chamber but only a quarter cycle. This means that the transit time through such a facility would be only 1.25 times the cycle length.

When an installation of two additional small lock chambers is considered, giving a system of three small locks working in parallel and presumably with staggered lock cycles, we may similarly find that the transit time through the total facility will be 1.17 times the cycle length. Since the assumed cycle length is 20 minutes or 0.33 hours, the transit times through the proposed single and dual additional small locks will be 0.42 and 0.39 hours respectively. Since the proposed multi-lane lock was assumed to have approximately the same operational characteristics, both hydraulically and otherwise, as the present small lock but capable of at least double the traffic capacity, transit time through this facility, remembering that it will interact with the presently existing installation, will be the same as for one additional lock chamber of the same dimensions as the small lock or 0.42 hours.

The number of vessels that would be diverted from the present large lock to these proposed facilities is quite easy to determine. We have subjected the quadruple track marine railway having a capacity of 36 vessels per hour to a detailed analysis. It seems more than reasonable to assume that a single additional small lock would pass a proportional amount of traffic, that is 30/36 or 5/6 of that already calculated for the four-lane marine railway. Figures based on this ratio are entered in the appropriate locations in Table 20.

We have already mentioned that two additional small lock chambers give us a capacity of 60 vessels per hour in excess of that presently available. Such capacity is undoubtedly equal to, or greater than, the practical sustained traffic handling capacity of the large lock. For this reason a facility consisting of two additional small lock chambers

will be assumed to be capable of carrying the full load of non-incidental traffic calculated in column H of Table 19. These figures have been transferred directly to Table 20. For the same reason these same figures are assumed to be representative of the amount of traffic that would be diverted into a multi-lane lock and are shown again in the portion of Table 20 appropriate to this facility.

## Computation of Estimated Travel Time Savings

At this state, Table 20 contains all information necessary to the calculation of savings in travel time by means of equation 20. The term:

$$t_1 - t_f$$

may be evaluated by subtracting the transit times for the proposed facilities as listed in column B of Table 20 from the transit time for the large lock as listed in the same column of the same Table. This is the difference in transit time that may be achieved through the installation of any one of the proposed facilities and is listed in column C. This value when multiplied by the estimated number of vessels that would have been diverted to these new facilities during the past several years, as tabulated in columns D through I, gives the values of total savings in travel time, in vessel hours, for these years for each facility and are tabulated in columns J through O.

We now have available to us all information necessary to estimate the justifiable cost of the various proposed improvements to the locks.

# CHAPTER VII

## JUSTIFIABLE COSTS OF IMPROVEMENTS

### Review of Methodology

Referring once again to Chapter 4, it will be remembered that an equation was developed incorporating all necessary factors and concepts required to calculate the justifiable initial cost of investment in any one of the proposed improvements of the locks. This relationship equated the justifiable original investment to the total annual savings in travel time occasioned by a given facility, multiplied by the value of time to yachtsmen using the facility, multiplied again by a constant dependent upon various factors including maintainance requirements, interest rate, and service life.

After making the requisite assumptions, values of the constant K were tabulated in Table 6. In Chapter 5 the results of the survey of yachtsmen using the Lake Washington Ship Canal were manipulated as required to calculate the value of time to these users, this value being $10.56 per hour for the general boat population. It is worthwhile mentioning at this point that since only limited classes of vessels could pass over either of the two types of beltways proposed, this figure for the value of time will not apply to either of these facilities. It is however possible to calculate the value of time to be applied to each of these facilities by reference to Table 14. When the adjusted cost of ownership and operation of vessels per hour of use as tabulated in column J of Table 14 is appropriately weighted for the segments of the boat population using the single and double beltways respectively, values of time of $2.[illegible]5 and $12.36 are found to be appropriate for use with these facilities.

## Calculation of Justifiable Cost

The calculation of the justifiable cost of each of the proposed facilities is carried out in Table 21. The facility under consideration is identified in column A of this table and the constant and value of time appropriate to each facility are listed in columns B and C. Columns D through I contain a listing of the savings of travel time in vessel hours as calculated previously. By means of equation 15 then, justifiable costs for each facility under the traffic load of each of the years shown in the column headings are calculated and listed in columns J through O. These figures have been rounded off to the nearest thousand dollars since no greater pretense of accuracy could possibly be justified on the basis of the assumptions made.

Originally, it was the author's intention to display graphically the variation in justifiable cost for these facilities considered. Upon attempting to do this however, it was found that the calculated justifiable cost depended principally upon the variation in traffic patterns at the locks rather being correlated with time or with gross number of pleasure craft through the locks. The numerical form in which the results of this investigation are presented in Table 21 seems to be the best display of this information possible.

## Desirability of Proposed Projects

First of all, with regard to time, it may be seen that the justifiable cost of all projects listed in Table 21 were at their highest level

TABLE 21

CALCULATION OF JUSTIFIABLE COST

| A<br>Facility | B | C<br>Value of Time<br>Dollars per Hour | D | E | F<br>Savings in Travel Time<br>Vessel Hours per Year | G | H | I | J | K | L<br>Justifiable Cost<br>Dollars | M | N | O |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 |
| 2 Track Marine Railway | 4.525 | 10.5 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 334000 |
| 3 Track Marine Railway | 4.525 | 10.5 | [illegible] | [illegible] | 10592 | 10821 | 9734 | 11392 | [illegible] | 475000 | [illegible] | 517000 | [illegible] | 544000 |
| 4 Track Marine Railway | 4.525 | 10.50 | 13582 | 14028 | 14905 | 15271 | 13780 | 15711 | 888000 | [illegible] | 712000 | 730000 | [illegible] | 751000 |
| Single Beltway | [illegible] | [illegible] | 5341 | 4202 | [illegible] | 4573 | 3121 | 4124 | 4700 | 41000 | 45000 | 45000 | 31000 | 40000 |
| Dual Beltway | [illegible] | 12.37 | [illegible] | [illegible] | 14405 | 15391 | [illegible] | 13880 | 933000 | [illegible] | [illegible] | 731000 | [illegible] | [illegible] |
| Single Lock | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Dual Lock | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] Lock | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

in 1958. Justifiable costs dropped sharply in 1959, rose in 1960 and 1961, dropped off again in 1962 and rose again somewhat in 1963. This illustrates quite clearly the way in which peaks in traffic flow have tended to spread out in later years under the influence of congestion pressure in the system. There is an implied suggestion here that the justifiable cost of improving the present installation at the locks may not rise in proportion to the total increase in traffic flow through the system.

Considering the desirability of individual facilities, it is obvious that the justifiable cost of the single beltway which can handle only flat bottomed outboard motorboats and centerboard sailing craft is so low as to be well below the limit of possibility. The justifiable cost of the dual beltway, on the otherhand, is quite high, but one must remember that this proposal presupposes the possibility of constructing a beltway capable of handling vessels having large underwater projections. This and the fact that such a beltway would have to handle a great variety of widely differing hull forms imposes nearly insuperable design problems upon this proposal.

Examining the proposals involving construction of additional locks, we see that in 1958 (the year of greatest justifiable cost), a single additional lock chamber would have accrued benefits sufficient to justify an investment of well over three-quarters of a million dollars while two parallel small lock chambers would have accrued benefits justifying an expenditure of over a million and a quarter dollars. Concurrently we see that the justifiable cost of the proposed wide, multi-lane lock in 1958 would also have been nearly a million and a quarter dollars. This, while

an impressive sum, would not be sufficient to actually construct the proposed facilities. The cost of the present double lock and a dam, built in 1916, was about two and a quarter million dollars (12). Since then, the Engineering News Record construction cost index has risen from about 120 to about 900 or 7½ times (13). This means that today it would cost over sixteen and a half million dollars to duplicate the present installation. Obviously, when viewed in this light, one and a quarter million dollars would not go very far towards building the proposed additional locks.

Turning now to the consideration of marine railways we find only a slightly more encouraging situation. In order to handle the traffic loads occurring in the year 1958, an expenditure of $360,000 would have been justified upon a two track marine railway. The three track facility would be better since the addition of only half again as much track would justify an expenditure of three-quarters again as much money. The four track arrangement is better yet, the installation of a third again as much track justifying the expenditures of more than a third again as much money. Since it provides the greatest capacity the four track railway is the most desirable of the three sizes. The question of course, is whether or not such a project could actually be built with the $888,000 indicated as the justifiable cost of such a structure.

From a cost standpoint, marine railways and beltways are attractive since they do not require the expensive building of temporary coffer dams necessary for construction of an additional lock. In addition, if a railway installation could be designed with operational characteristics superior to the rather severely limited characteristics assumed in this study, such

an installation would have an even greater justifiable cost.

## Other Factors to Consider

It has been pointed out that the justifiable cost of all proposed projects has been less in later years than in 1958. Although we were not able to plot the effect of time upon the fluctuation of justifiable cost, we may assume that it will rise more or less in proportion to the projected increase in traffic through the ship canal system as projected in Figure [illegible]. Again it must be pointed out that since justifiable cost seems to be dependent upon the traffic pattern rather than gross pleasure craft traffic through the locks, we cannot say that when the gross traffic reaches its 1958 density, justifiable costs of proposed facilities will have reached their 1958 high. It is, however, probably safe to predict that these justifiable costs will, in fact, be reached in the foreseeable future barring major fluctuations of the national economy. The temporal variability of the justifiable cost of improving the locks is a factor of which all interested agencies should be mindful even if not engaged in active study of the congestion problem.

It is also well to remember that this thesis does not contain the final word either on the total variety of possible improvements at the locks or on the total benefits to be gained therefrom. The direction of an ingenuity superior to the author's upon the problem of devising some remedy could quite conceivably produce a solution combining great enough traffic handling capacity with a low enough initial cost to be immediately and obviously desirable. Extended study of the congestion problem should

enable much more precise calculation of the magnitude of benefits to be gained from possible improvements than has been made in this investigation. In addition there unquestionably are large benefits to be gained by commercial establishments, both by those connected directly with the boating industry and those which are simply users of waterways, which have not been considered in the slightest herein. The isolation of these additional benefits can have no other effect but to make any proposed solution to the congestion problem appear more beneficial.

It should be pointed out that the previous comment concerning the operational characteristics of marine railway installations applies equally to all other types of proposed facilities. If any of these types of installations are found to have operational characteristics superior to those assumed herein, the effect would be to enhance the desirability of that particular type of installation.

## Effect of Comparison With Other Projects

In the past several pages we have repeatedly spoken rather blithely of "justifiable cost." It must now be stated, or perhaps restated, that this justifiable cost is the maximum investment permissible if no more stringent criterion other than absolutely marginal profitability (which is to say no profitability at all) is imposed upon the decision to construct the improvement under consideration. If we compare these projects with some other series of projects, say a group of proposed highway improvements, which are of greater than marginal benefit to the public, then in comparison our proposed lock improvements are even less favorable than they

appear already. If, for instance, we compared our proposed lock improvement with a project having a benefit/cost ratio of 2, then to permit correct comparison we would have to halve all of our calculated justifiable costs. All of our proposed improvements then are likely to suffer by comparison to other potential public projects. This line of reasoning leads the author to the general conclusion that no physical improvement of the locks will be undertaken in order to relieve the present level of congestion in the ship canal system, nor, since there is no plan for any extended study of the congestion problem presently in existence, does any physical improvement of the locks seem likely in the foreseeable future.

## Administrative Measures for Congestion Relief

The early pages of Chapter 3 discussed several possible means of reducing congestion in the ship canal system by use of educational programs, streamlining of administrative procedures and traffic information distributing systems. In view of the conclusions drawn above, measures of this sort would seem to be the only recourse of agencies desirous of reducing congestion in the ship canal. Most such measures would appear to be relatively cheap and the evaluation of the reductions in congestion which might thereby be obtained, while beyond the scope of this thesis, would seem to be the next logical step in any effort to improve the present situation.

# CHAPTER VIII

## MORE EXTENDED STUDIES OF SHIP CANAL CONGESTION

For reasons that for the most part have already been mentioned, it may well be desirable for some agency, organization or individual to undertake a more extensive investigation of the problem of traffic congestion in the Lake Washington Ship Canal. Some of the effort involved in such a study might possibly be directed toward elimination of some of the numerous inadequacies of the present investigation. It is the purpose of this chapter to discuss some of these inadequacies and the ways in which more extensive study can be employed in their elimination.

### General Theory

In order to eliminate excessively burdensome calculations, this thesis employed numerous simplifying assumptions to, and mathematical manipulations of, the benefit/cost ratio which would not be required in a study not operating under the constraint of severe budgetary and personnel limitations. Such a study could operate on a considerably extended theoretical basis such as might be founded upon the combination of equation 3 with equation 12. There can be little doubt that the extended categorization of benefits and costs thus obtained would lead to increased accuracy. Whether or not such increased accuracy justifies the increased effort is of course, a matter which must be left to the discretion of the agency or individual considering such an undertaking.

Another extremely serious criticism that may be leveled at the present study is its tacit assumption of marginality. This deficiency could be attacked by any one of several avenues of approach. Estimates

could be made of the actual cost of constructing proposed projects and these used to calculate the benefit/cost ratio directly. A minimum acceptable rate of return could be used in a rate of return type calculation, a minimum acceptable benefit/cost ratio could be applied, or the benefit/cost ratios or rates of return achieved on projects already in existence or competing with the proposed project for acceptance could be substituted as a decision criterion.

## Proposed Facilities

One very important area that should be researched during an extended study of this problem is that of the universe of conceivable solutions and reliefs to the congestion problem. The problem, if solved, is not likely to be solved by attacks along conventional lines. Innovation and ingenuity will be the keys to success if success is in fact obtainable.

Also of great importance is that factual operational characteristics could be obtained and utilized during an extended study. The operational characteristics used in the present investigation, while rational and based to a great extent upon available literature and the opinions of professional engineers, are nevertheless subjective and not necessarily completely representative of reality.

## Determining the Value of Congestion Reductions

The methodology used by an extended study to determine the economic value of reductions in congestions in the ship canal would depend to a

great extent upon the type of economic analysis employed. The [illegible] expanded theoretical expression for determination [illegible] accompanied by [illegible] greater [illegible] classes [illegible] such a general [illegible] all [illegible] the effects of food [illegible] will be an increase [illegible] whether or not such an increase [illegible] is just [illegible] to [illegible].

[illegible] would [illegible] tendency [illegible] of [illegible] ability. [illegible] would [illegible] food [illegible] at the [illegible].

[illegible] should prove [illegible] value [illegible] study of [illegible] problem [illegible] that [illegible] results could be obtained [illegible] in a [illegible] rather [illegible] employed in this [illegible] type [illegible].

[illegible] limitations [illegible] basic [illegible] the collection of [illegible] large sample [illegible] that caused [illegible] solution [illegible] would [illegible] greater [illegible] accuracy [illegible]

would eliminate the necessity of manipulating a biased sample by means of only subjectively justified adjustments.

## Other Economic Factors

The present investigation considered only the benefits that would be conferred upon pleasure boat owners by improvements at the locks. An extended study could expand this universe to detect the benefits that would be conferred on commercial users. Also the present study considered only those benefits that would accrue directly through reductions in travel time required to transit the locks. A more comprehensive treatment of this problem could include research on the effect of reductions in accidents, reductions in Coast Guard equipment and personnel required to police the canal, reductions in City of Seattle Harbor Police equipment and personnel required, the effects of water losses through the locks and the effects and the reductions or increases in bridge openings at the various spans crossing the ship canal.

An expanded study could also consider the effects of reductions in congestions on the boating industry in general, on other maritime and otherwise interested and affected industries, and the economic impact of congestion or lack thereof on the general economy of the Greater Seattle Area. There is some tendency to view these rather remote economic effects as transfer effects which are direcly attributable to variations in the cost of transportation itself and not directly meritorious of consideration as independent benefits to the general economy. While there is some justification to this view, the author feels that transportation benefits have a regenerative effect of the kind known to occur

in the economics of money and banking. The degree to which transportation benefits are thus regenerative would be one of the areas of research worthy of consideration of any agency undertaking a more extended study of the ship canal congestion situation.

## Travel Time Savings

The importance of travel time savings occasioned by improvements in the ship canal system to the calculation of the benefits conferred by such an improvement is primarily dependent upon the mathematical approach employed. In the present study all benefits were held to be dependent upon travel time savings. In the extended, compartmentalized approach an additional study would probably employ, travel time savings will be at least to some degree less significant. On the basis of the research into the value of time incident to this thesis however, the author is firmly convinced that travel time savings must play a large part in any determination of benefits occasioned by reductions in congestion at the locks.

Lacking both the time and personnel necessary for a more detailed consideration of travel time savings, the present study made a number of unsatisfactory assumptions, simplifications and approximations. Savings in travel time were assumed to be gained by diversion of traffic from the present large lock to some proposed facility. This is an oversimplification since a facility providing more expeditious passage than that obtainable from the small lock would also drain off traffic from that installation. The average transit time through the locks was assumed to

be 1.5 times the cycle length. This presupposes that no vessel waits longer than one full cycle for admittance to the lock chamber. This is not true. Particularly at high traffic arrival rates, some vessels must wait considerably longer than this. Rather than correlating existing lock data with personal observations, techniques for reducing lock data were developed on a purely theoretical basis. Even then, the majority of the available voluminous lockage data were ignored for the sake of brevity with only the most compact presentations of this data employed.

Supposing that more extensive resources of time, personnel and funds were available for additional study, most of these defects could be remedied. Teams of observers could be stationed both above and below the locks, each craft approaching the locks could be identified, timed in its passage, and afterwards halted and questioned for requisite data. If such a program were carried out for a full year and the results analyzed by modern electronic methods, it would be possible to develop relationships from which not only could travel time savings during the current year be calculated but which could be used for correlation of already existing records of lockage and subsequent calculation of travel time savings in previous years. Obviously more extensive time and personnel resources would make possible the reduction of the present extensive records of lockages in previous years to formats suitable for electronic data processing.

## Other Methods and Considerations

The possibility of adapting the techniques of electronic data processing to the keeping of lock records has already been commented upon in

Chapter 3. Such a step would make possible continuing, precise, mechanized study of lock operations, a most desirable situation in view of the tendency of traffic patterns at the locks to fluctuate with time. Such an automated system would not however, obviate the need for human observation of ship canal traffic although it would probably reduce the amount of such observation required.

Simulation of operations at the locks by means of an electronic computer is an intriguing possibility. With appropriate input data, such a program would not only be able to predict the pattern of work operations to be expected under future traffic loads but would also enable the calculation of travel time savings to a superior degree of accuracy.

As a matter of fact, Mr. Kenneth Dueker, Research Instructor of the University of Washington Department of Civil Engineering, Transportation Division, is presently experimenting with a computer simulation of the Hiram M. Chittenden Locks. The results of his experiments should be of considerable interest to any person or agency considering additional study of the ship canal system.

One additional possibility that might be worth considering is research into the question of whether or not the more constricted portions of the ship canal system are approaching their maximum traffic handling capacity and what effect this will have on the situation at the locks. It is obviously uneconomical to expand the traffic handling capacity of the locks past the traffic handling capacity of the canal itself and extensive enlargements of the canal would be almost prohibitively expensive.

# CHAPTER IX

## THE FUTURE OF SEATTLE PLEASURE BOATING

### The Locks

Whether or not any action is taken to improve congested conditions in the ship canal and at the locks is certainly not dependent upon the results of this thesis. Even had this investigation concluded that immense benefits were to be gained from improving the locks, it is doubtful whether any such action would in fact have been taken. As it is, the author has concluded that increasing the traffic handling capacity of the locks by other than administrative means is uneconomical at the present time and can offer no greater encouragement than to say that more extensive study will undoubtedly reveal flaws in the author's theory and methodology as well as revealing benefits to be gained from areas of economic activity not considered herein. Under any circumstances, the author cannot foresee any expansion of facilities at Hiram M. Chittenden Locks being undertaken within the predictable future.

### The Boat Population

Assuming continuance of the present general prosperity and the resulting continued harvest of the fruits of automation, the American public, flushed with leisure and lucre, will undoubtedly pursue happiness in aqueous surroundings with increased intensity. The boat population upon every scrap of surface water extant within our borders must be

expected to rise exponentially; even more so the boat population upon those waters contiguous to the limitless expanses of the sea. In consequence the boat population upon the waters in vicinity of greater Seattle must be expected to increase, and with it the congestion in the ship canal and at the locks. As this congestion increases to levels not heretofore obtained, it must be expected to exert a depressing, or restraining effect upon its own continued expansion. This self-limiting effect will of course exert a corresponding influence on the boating industry in general, though in unpredictable proportions, due to the previously mentioned regenerative effect of transportation cost transfers.

## The Shift to Salt-Water

The pressure of congestion in fresh-water areas will result in increasingly greater numbers of boatmen mooring directly upon salt-water and seldom venturing inland of the locks. The expansion of salt-water based boating will to a greater or lesser degree compensate for the depressing influence of fresh-water congestion. Eventually, the centre of gravity of pleasure boating activities may be expected to shift to seaward of the locks. Such a shift however, is not likely to take place in the immediate future since the continued increase of boat density in fresh-water will continue to make these areas more attractive to potential investors with the result that salt-water facilities may be expected to expand at a disproportionally slow rate.

## The Last Word

Whatever the pattern of development of pleasure boating in the Lake Washington Ship Canal System, it is unlikely that any analysis of it will be made which is more penetrating than that said to have been made more than a century ago by Quillayute, chief of the Chinook Indians when he said, '"Delate Canim Okeoke Chuck." By and by many canoes on that water.'

# APPENDIX [illegible]

## TYPICAL VESSEL DIVERSION ESTIMATE BY MARINE RAILWAY

The succeeding paragraphs of this appendix describe in detail, for those who are interested, the rather involved logic employed in making the required estimates of the number of vessels that would be diverted from the present large lock to a marine railway installation. The specific example considered is the year 1958 but the same process of course, applies to all other years.

In Column B of Table 17 are listed those days during which ten or fewer vessels passed through the large lock. It will be assumed that these amounts of traffic represent incidental lockages in company with larger commercial vessels, etc., and would result in no diversion of traffic to proposed facilities, thus zero has been inserted in the appropriate locations of Table 17.

Column C of Table 17 lists those days during which the traffic was between 11 and 50 vessels per day. Since this is a relatively low traffic rate and must of necessity represent a relatively low rate of arrival of small craft at the locks, it will be assumed that all of our proposed marine railways, even the minimum two lane installation, will be fully capable of handling this load. It will also be assumed that there will still be ten craft which pass through the large lock in incidental lockages. The mean between the limits of 11 and 50 vessels per day is a flow of 30 vessels per day which is a flow of 20 vessels per day above the level of 10 vessels per day attributable to incidental lockages. For the year 1958, 20 vessels per day times 77 days at which this rate of flow occurred gives 1540 vessels that would be diverted into our proposed

facilities on these days. Note that since this figure represents the full divertable traffic on these days, the same figure will apply to the three and four-lane railways as well as to the two-lane installation. Calculations for all other years are of course similar and are recorded in Table 17.

Column G of Table 17 lists days lying between the limits of 50 and 100 vessels per day, the mean daily flow rate being 75 vessels per day, or 65 vessels per day greater than incidental flow. If the rate of flow through the large lock were assumed to be about 30 or 32 vessels per cycle, then it would take about two cycles of that lock at 55 minutes or 0.917 hours per cycle to pass this amount of traffic. This is equivalent to about 1.83 hours during which a double-lane marine railway could transfer about 22 vessels and the triple-lane arrangement could transfer 44. Since the four-lane railway could pass 66 vessels, a number greater than the mean non-incidental daily traffic, it will be assumed that the quadruple installation will be able to achieve 100% diversion or a daily flow between 51 and 100 vessels per day. For the year 1953 this would have amounted to 440, 880 and 1300 vessels that would have been diverted into the three sizes of marine railway.

Column H of Table 17 lists days on which the traffic through the large lock was between 100 and 200 vessels per day, the mean being 150 vessels per day, 140 above incidental traffic. At any chamber loading of the large lock less than 46 vessels per cycle, it would take 4 cycles to move this many vessels. This would require about 3.67 hours enabling the three proposed sizes of marine railway to transfer 44, 83 and 132 vessels

respectively; resulting in values of 836, 1672 and 2508 as the number of craft each of the three facilities could have moved during these days in the year 195[illegible].

For calculations involving the limits of 200 through 600 vessels per day as shown in columns I, J, K and L of Table 17, it is assumed that the practical limit of normal chamber loading of the large lock is about 50 vessels per cycle. The number of required cycles of the large lock was then calculated; rounded off to the next largest even number of cycles; the time required to complete these cycles computed (at 0.917 hours per cycle); and this required time multiplied by the assumed rates of traffic flow over our proposed facilities of 12, 24 and 36 vessels per hour. The number of vessels per day that could thus be diverted are shown in column D of Table 18, and the actual number of craft that we may assume capable of diversion at varying traffic flows during the past six years are shown in columns E through J of this table.

In column M of Table 17 is listed the number of days during the past six years on which more than 600 vessels passed through the large lock, and in column N is listed the actual number of vessels that passed that lock on each of these days. For these days, the number of vessels that would have been diverted to our proposed facility is calculated by totaling up the actual number of vessels that passed through the large lock; subtracting ten for incidental traffic for each day over 600; dividing by 50 vessels per cycle assumed chamber load; rounding off to the next even cycle; multiplying by 0.917 hours per cycle and then multiplying by the hourly traffic capacity of each of our proposed facilities. All columns

of Table 19 are then totaled and the results recorded in Table 20.

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